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SURVEYING NON-MOTORIZED TRAVEL BEHAVIOR AT AT-GRADE RAIL CROSSINGS

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16. Abstract

Train-pedestrian collisions have been shown to be the leading cause of fatality in train-related accidents worldwide, yet there is remarkably little research examining non-motorist travel behavior at grade crossings. This report aims to determine how non-motorists behave and interact near at-grade rail crossings, including their level of compliance with existing safety treatments and crossing signals. This will allow DOTs and rail agencies to better coordinate their efforts to promote safety while accommodating actual non-motorist behavior trends. To evaluate these interactions and behavior we compiled environmental inventories and collected data on non-motorist behavior at 26 at-grade rail crossings along Utah's Wasatch Front. This included observations of 1,459 non-motorist crossings. Results suggest that a simple approach may in fact be safer when it comes to safety controls and infrastructure at crossings. Visual obstructions, and a lack of barriers and flashers was significantly correlated to more non-motorists exhibiting risky behavior. However, the presence of channelization (e.g. z-gates) and blank-out signs was significantly correlated to more risky behaviors among non-motorists. Crossings with more travel lanes, bike lanes, visual obstructions, a school zone near the crossing, or the presence of ADA accommodation were correlated to fewer distracted non-motorists. Additionally, crossings with a detectable warning surface (DWS) in the non-motorist area exhibited 23% fewer pedestrians crossing in compliance, as pedestrians tended to walk around them.

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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
APS	Audible Pedestrian Signal
AREMA	American Railway Engineering and Maintenance-of-Way-Association
ATV	All-Terrain Vehicle
DWS	Detectable Warning Surface
FHWA	Federal Highway Administration
Fps	Feet per second
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HCM	Highway Capacity Manual
LRT	Light Rail Transit
LRV	Light Rail Vehicle
HSIP	Highway Safety Improvement Program
ML	Maximum Likelihood
MOI	Manual of Instruction
MUTCD	Manual on Uniform Traffic Control Devices
NTSB	National Transportation Safety Bureau
OLI	Operation Lifesaver
TRB	Transportation Research Board
TCRP	Transit Cooperative Research Program
TOD	Transit Oriented Development
UDOT	Utah Department of Transportation
UDPS	Utah Department of Public Safety
USDOT	United States Department of Transportation
UP	Union Pacific
UTA	Utah Transit Authority

EXECUTIVE SUMMARY

Train-pedestrian collisions have been shown to be the leading cause of fatality in train-related accidents worldwide, yet there is remarkably little research in this area. While specific best practices and engineering guidance are provided in the UDOT Pedestrian Grade Crossing Manual (2013) and other available resources, they do not consider the specific environmental contexts or human travel behavior. This research seeks to analyze non-motorized travel behavior at rail grade crossings to determine: 1) What is the current level of compliance with existing non-motorized safety treatments? 2) Do non-motorists exhibit risky behaviors at crossings? 3) Does distraction play a large role in non-motorist behavior at crossing? and 4) What other notable travel behavior characteristics are present during non-motorized rail crossings.

Data was collected and analyzed for 26 at grade rail crossings along the Wasatch Front including ten crossings in Salt Lake County, four in Weber County, five in Davis County, and seven in Utah County. A combination of 30 specific transportation system, built-environment and other site characteristics were collected for each location. Data was collected using a combination of field visits and electronic aerial photograph analyses. Each crossing location was visited on at least two separate occasions for a two-hour interval. The first visit was intended to confirm built environment and transportation system data previously collected electronically. The second site visit was used to evaluate user experience and monitor non-motorized access to stations. A total of 1,459 non-motorists were observed and their crossing behavior was catalogued for this analysis.

A number of Maximum Likelihood and Poisson regression models were employed to examine relationships between non-motorist travel behavior and built-environment characteristics. For these analyses non-motorist behavior was categorized into three distinct areas: compliance with existing routing, signage, and signals; exhibition of risky behaviors; and the presence of distraction. In order to ensure that the analysis provided was robust and comprehensive, a large number of additional variables were included in various iterations of reach model to ensure that latent confounding variables did not skew the analysis and that collinearity was reduced or eliminated.

Several environmental and crossing characteristics were correlated to travel behavior at crossings. First, this analysis found that nearly 20% of the non-motorists observed did not follow the approved pathway through the crossing. Crossings that had a detectable warning surface (DWS) in the non-motorist area exhibited 23% fewer pedestrians crossing in compliance.

Next, an analysis found that nearly 20% of the non-motorists observed in the sample exhibited at least one risky crossing behavior. These included lingering on the tracks rather than crossing quickly (4.2%), disregarding signals or signage (15.9%), crossing through cross-arms once they have lowered or as they are lowering (3.7%), walking around gates or barriers (17.2%) and walking into vehicular traffic, typically to avoid existing barriers and gates (18.4%). Visual obstruction was significantly correlated to approximately 22% more non-motorists exhibiting risky behavior. The absence of barriers and flashing light signals was significantly correlated to more non-motorists exhibiting risky behavior, while the absence of channelization, blank-out signs, and detectable warning surfaces (DWS) was significantly correlated to fewer risky behaviors among non-motorists.

Lastly, non-motorist distraction was evaluated. Approximately 12% of those observed were distracted in at least one way, with many exhibiting multiple distractions. The most common distraction was an electronic device (e.g. cell phone, tablet, etc.) often accompanied by wearing headphones (8.6%). Regression analysis found that the number of travel lanes, the presence of a bike lane, visual obstructions, a school zone near the crossing, and the presence of ADA accommodation were significantly negatively correlated to non-motorist distraction. Because these add to the complexity of the environment they may encourage non-motorists to pay better attention while crossing. It is notable that neither the presence of non-motorist accommodations or pavement markings were significantly correlated to non-motorist distraction at the crossing.

It is recommended that in an effort to improve safety at at-grade rail crossings that UDOT improve education regarding detectable warning surfaces (DWS) and signage at crossings (including blank out signs). This education can be integrated into existing programs such as Operation Lifesaver. Additionally, UDOT should work with UTA to reduce visual obstructions around crossings and work to ensure appropriate barriers are in place to channel pedestrians to safe crossing locations.

1.0 INTRODUCTION

1.1 Problem Statement

Train-pedestrian collisions have been shown to be the leading cause of fatality in train-related accidents worldwide, yet there is remarkably little research in this area (Lobb, 2006). The Utah Department of Transportation (UDOT) has taken a proactive approach to promoting pedestrian and cyclist safety at at-grade rail crossings by providing for efficient operations of trains and vehicles while also providing non-motorized access through grade crossings. While specific best practices and engineering guidance are provided in the UDOT Pedestrian Grade Crossing Manual (2013) and other available resources, they do not consider the specific environmental contexts or human travel behavior. Rather, these exogenous variables are left to be identified by a separate Diagnostic Team for each location. One of the keys to developing safer rail crossing designs is to gain a better understanding of pedestrians' behavior as they interact with crossing infrastructure. For example, how vigilant are pedestrians when using a crossing? Is risky behavior rare or commonplace? Are particular demographic groups more inclined to take risks than others? How do pedestrians with disabilities navigate a rail crossing safely?

1.2 Objectives

This research conducted a site survey of a sample of at-grade rail crossings, including existing conditions and compliance with the guidelines provided in the UDOT Pedestrian Grade Crossing Manual. Additionally, site observations were performed to analyze non-motorized travel behavior at rail grade crossings to determine:

- What is the current level of compliance with existing non-motorized safety treatments?
- Do non-motorists exhibit risky behaviors at crossings?
- Does distraction play a large role in non-motorist behavior at crossing?
- What other notable travel behavior characteristics are present during non-motorized rail crossings?

This analysis will provide UDOT Diagnostic Teams with additional agent-based information allowing for a data-driven analysis of pedestrian hazards, and a more tailored determination of appropriate safety treatments at each location.

1.3 Scope

This study utilized data collected from 26 at-grade rail crossings in Weber, Davis, Salt Lake, and Utah Counties. Using a combination of aerial photos, GIS data collection, and on-site visits, additional built-environment and transportation system data was collected for each location. Train frequency data was compiled at all crossings, and demographic data were collected for residents living within ¼ mile of each crossing using current U.S. Census projections. Lastly, on-site counts were compiled of non-motorists as well as vehicles at each crossing and observations were made regarding non-motorist crossing behaviors. A profile of each station was created by using both quantitative and qualitative observational methods.

1.4 Outline of Report

The report is organized into six sections, as follows: Section 2 provides a brief literature review examining walkability, access to transit, and a summary of the current state of knowledge regarding pedestrian and bicycle safety near rail stations. Section 2 also includes a description of the study methods and justifications. Section 3 presents the study data collected and provides summary characteristics for the crash reports. Section 4 presents both qualitative and quantitative analysis of the observed non-motorized travel behavior. Section 5 provides conclusions based upon the data provided in the previous sections and Chapter 6 outlines the author's recommendations for implementation.

2.0 RESEARCH METHODS

2.1 Overview

A thorough literature review was performed on pedestrian and bicycle infrastructure and behavior surrounding at-grade rail crossings. This chapter provides background information on highway-rail crossings, rail-highway safety, and non-motorist travel behavior near rail crossings. It also includes a discussion of the research methods employed and the justification for each.

2.2 Background

While there are well-defined standards for vehicle rail crossing design, current national standards for pedestrian rail crossing design are less comprehensive. Rail operators and governments worldwide have acknowledged the need to develop better standards for rail crossing design, particularly when considering the needs of non-motorists or people with disabilities (Wheelchair Safety, 2002).

One of the keys to developing safer rail crossing designs is to gain a better understanding of pedestrians' behavior as they interact with crossing infrastructure. For example, how vigilant are pedestrians when using a crossing? Is risky behavior rare or commonplace? Are particular demographic groups more inclined to take risks than others? What role does distraction play in crossing safety? How do pedestrians with disabilities navigate a rail crossing safely?

At-grade highway-railroad grade crossings are locations where a highway crosses a railroad surface at the same elevation. They are also called level crossings in other countries such as Canada, Australia, and the United Kingdom. Warning or traffic control devices are required at at-grade crossings just like roadway intersections to avoid collisions. According to the Federal Rail Administration (FRA) "Active Grade Crossings have active warning and control devices such as bells, flashing lights, and gates, in addition to passive warning devices such as crossbucks (the familiar x-shaped signs that mean yield to the train), yield or stop signs and pavement markings. While passive Grade Crossings have only passive warning devices", such as signage (FRA, 2014). These warning/control devices are specified in the Manual on Uniform Traffic Control Devices (MUTCD).

Grade crossings may be public or private. Public grade crossings involve roadways that are under the jurisdiction of, and maintained by, a public authority. Private grade crossings are on privately owned roadways, such as on a farm or in an industrial area, and are intended for use by the owner or by the owner's licensees and invitees. A private crossing is not intended for public use and is not maintained by a public highway authority. While Utah has over 1,300 at-grade rail-highway crossings, only about 700 are in the public right-of-way (FRA, 2018).

2.2.1 Safety Statistics

Collisions between highway vehicles and trains have been, until recently (1996), the greatest source of injuries and fatalities in the railroad industry. As a result of the Grade Crossing Action Plan, and the continuous research effort funded by the FRA, the number of fatalities and injuries at grade crossings decreased by almost 40 percent between 2001 – 2011 and had a slight increase in 2014. In the same time period, trespassing fatalities decreased by approximately 21 percent, but increased by 29% between 2011 and 2014 (FRA, 2014).

Non-motorists are particularly vulnerable near trains. According to Operation Lifesaver, it takes the average freight train traveling at 55 mph (approximately 90 kph) more than a mile (1.6km)—the length of 18 football fields—to stop (Operation Lifesaver, 2018). A train can extend three feet (1m) or more beyond the steel rail, putting the safety zone for pedestrians well beyond that. In 2017 over 20% of Utah’s highway-rail incidents involved pedestrians, compared to only 7% nationally (FRA, 2018b). Approximately half of the state’s pedestrian involved rail crashes were suicide casualties (FRA, 2018c).

While deaths at rail crossings in Utah represent less than 1% of the state road toll (UDPS, 2016), they often attract media and community attention. Much of the focus tends to be on vehicle accidents and derailments, yet fatality statistics show that the second most common type of rail fatality in the state is a pedestrian being hit by a train while crossing railway tracks (FRA, 2017). Additionally, Utah rail fatality statistics show that from 2014 vehicle-train collisions were down 25% while crashes involving a pedestrian at rail crossings were up 200% (FRA, 2017). The majority of rail collisions involve Union Pacific trains (38%), followed by UTA FrontRunner (28.2%) and UTA TRAX (25.6%) trains (FRA, 2017).

Today's trains are quieter than ever, and approaching trains are often closer and moving faster than people anticipate. Texting, headphones, and other distractions can prevent pedestrians from hearing an approaching train. Additionally, railroad trestles should not be used as pathways. There is often only enough clearance on the tracks for a train to pass. These side trestles are not meant to be used as sidewalks or pedestrian bridges. Never walk, run, cycle or operate all-terrain vehicles (ATVs) on railroad tracks, rights-of-way or through tunnels. Cyclists also face unique dangers near rail lines. Narrow wheels can get caught between the rails when crossing, and wet tracks can be slippery. Both pedestrians and cyclists face risks if they ignore existing traffic control devices, which they may believe are only for motorists. It is illegal to go around lowered gates whether on a bike, on foot or in a vehicle (Operation Lifesaver, 2018).

NTSB has identified rail transit safety oversight as a "most wanted" advocacy priority. They have identified that "ineffective safety oversight is a contributing factor in many rail transit accidents. It is critically important that rail transit systems be constantly monitored and improved to maintain and enhance safety so small problems can be caught before they become big ones (NTSB, 2017)."

2.2.2 Non-Motorist Behavior at Rail Crossings

In this report, the terms 'non-motorists,' and 'non-motorized users' will be used interchangeably to indicate crossing users who utilize pedestrian approaches to at-grade rail grade crossings. These users include pedestrians, pedestrians pushing a stroller, bicyclists (either on or off their bike), and users on rollerblades, in a wheelchair, or those using skateboards or scooters.

According to McPherson and Daff (2005), pedestrian travel behavior plays a significant role contributing to deaths at rail crossings (see Table 1). Their research specifically sought to establish the common pedestrian behaviors that may lead to injury or fatality at rail crossings, particularly in the categories of risk-taking and lack of awareness.

Table 1. Common Contributing Factors to Pedestrian Deaths at Rail Crossings

Category	Contributing factors
Lack of awareness	• Not aware of train approaching • Second train approaches shortly after first train
Entrapment	• Trapped on tracks (eg. fallen over, trapped wheelchair) • Insufficient time to cross for slow-moving pedestrians
Risk-taking	• Misjudgment of train speed • Trespass – playing or walking on the tracks
Deliberate	• Suicide • Homicide

*Source: McPherson and Daff (2005)

Lobb, Harre and Terry (2003) found that unsafe pedestrian crossing was significantly reduced through a combination of public communication, education and punishment. They found that punishment may be more effective in reducing unsafe behavior in this type of situation than targeted education and is much more effective than communications to heighten awareness.

A separate retrospective analysis of 25 pedestrian-train fatalities in Charleston, SC found that the victims were predominantly healthy, young males. All but one person died at the scene. The cause of death was massive blunt trauma in 88% of the cases. In one case, the sole injury was decapitation. A tissue or blood alcohol level greater than 99 mg/dL (0.10%) was detected in 80% of the cases. A total of 60% of the cases involved persons likely to have been sitting or lying across the railroad tracks; all but one of the victims were intoxicated. The manner of death was determined to be accidental in 92% of cases (Cina, Koelpin, Nichols and Conradi, 1994).

The UDOT Pedestrian Grade Crossing Manual states that "risky pedestrian behaviors should be observed and taken into consideration (UDOT, 2013)." Examples of risky pedestrian behaviors that have been observed in Utah include:

- Standing on a detectable warning surface
- Distracted pedestrians
- Not looking both ways
- Disregard for existing safety devices

Suicide and Trespass

According to the National Transportation Safety Bureau (NTSB) suicides and trespassing accidents result in nearly 500 annual fatalities nationwide, representing 75% of all fatalities occurring within the American railway system (NTSB, 2016). Trespassing incidents involve individuals who are trespassing on railroad rights-of-way at locations other than authorized grade crossings, including overhead and underground crossings. While nearly all suicide incidents that occur on the tracks involve trespassing, it is difficult to definitively determine if a fatality is in fact a suicide, as the deceased is unable to identify the intent of their actions.

RESTRAIL was a 3-year EU FP7 research project that aimed to help reduce the occurrence of suicides and trespasses on railway property and the costly service disruption caused by these events. The project was coordinated by the international Union of Trailways (UIC) and provided the rail industry and researchers worldwide with an analysis of the most cost-effective prevention and mitigation measures (Havarneanu, Bonneau, and Colliard, 2016). This research identified five relevant issues - 1) Collection of data and analysis related to railway suicides and trespass incidents; 2) Assessment of preventive measures to reduce railway suicide and trespass; 3) Assessment of measures to mitigate the consequences; 4) pilot tests to evaluate measures in the field; and 5) practical recommendations and guidelines. Their conclusions included a list of 25 recommended measures, 11 field tests of effectiveness of measures, and an online toolbox for decision makers. Additionally, within the RESTRAIL project, Havarneanu, Burkhardt and Silla (2017) created a 6-step problem-solving model consisting of a multi-step approach "structuring the analysis of a suicide or trespass-related problem on the railways."

While "suicide by train" continues to be a problem for urban railways, 2017 saw the lowest number in 7 years. Data from the first quarter of 2018 suggest that the annual figure may be far lower than 2017 (FRA, 2018a). To better understand suicide near rail, the FRA conducted a study of the 55 suicide fatalities occurring on rail right-of-way from 2007-2010 (Berman, et al, 2013). The report found that:

- All of those who died had abused alcohol or drugs, and all but two suffered from mental illness
- At the time they stepped in front of the train, half had consumed alcohol or illegal or prescription drugs
- 84% of those who committed suicide were men
- The median age was 40 years old
- More than half suffered from a chronic physical illness that often caused pain (Berman, et al, 2013)

Further analysis of suicide incidents occurring from 2012-2014 found that "a number of environmental and individual factors are associated with each incident, such as location (region, state, and right-of-way vs. grade crossing), time (season, month, day of the week, time of day), and characteristics of the individual (age, gender, physical act that immediately preceded the incident)." The report also identified among individuals who committed suicide by rail, 96% were likely to have a mental disorder, 62% had a drinking problem, and 58% had a substance abuse problem (FRA, 2018a).

Entrapment and Lack of Awareness

When a vehicle or pedestrian/cyclist cannot fully cross the rail right-of-way and becomes physically trapped on the tracks at a grade crossing, it is referred to as "entrapment". These types of crashes can happen when the drivers are confused between the railroad and the roadway, or when they try to go around the gate systems when they are already activated (Jeng, 2005). These crashes can be related to human error and incorrect human information processing, aggressive driving behaviors, or inability to control the vehicle under a high pressure condition.

Incidents involving one or more violations at rail grade crossings differ from trespassing incidents away from crossings. Sposato, Bien-Aime, and Chaudhary (2006) note that these types of violations typically occur on three occasions: (a) when a pedestrian enters the crossing when the warning lights are flashing but before the gate arms have begun to move; (b) when a pedestrian enters the crossing while the gate arms are in motion, either in their descent (before train arrival) or ascent (after train departure); and, (c) when a pedestrian enters the crossing after the gate arms are in their horizontal position.

Although anecdotally we assume that distracted pedestrians are more likely to be involved in a collision with a train at a grade crossing, few data have been collected for research and quantification of distracted walking. Mwakalonge, Siuhi and White (2015) found that pedestrian behavior was considerably riskier when distracted with a mobile device than when they were undistracted.

Kuzel, et al (2008) reviewed an inventory of collisions involving pedestrians who were distracted. The review found that "highly salient and expected roadway objects such as buses, police vehicles, and trains have been involved in collisions with reportedly distracted pedestrians at or near standardized road crossing points". Their data also suggested that pedestrians distracted by auditory activities, regardless of their form, are likely to be sufficiently unengaged in the act of crossing or walking along a street to perform basic tasks safely.

A separate study by Lichenstein, et al (2012) utilized the National Electronic Injury Surveillance System, U.S. Consumer Product Safety Commission, Google News Archives and Westlaw Campus Research Databases for cases involving pedestrian distraction from 2004 to 2011. Their study analyzed 116 reports of death or injury involving pedestrians wearing headphones. Of all the reports, 74% stated that the pedestrian was wearing headphones at the time of the crash and 29% mentioned that a warning was sounded before the crash. The majority of victims were male (68%) and under the age of 30 years (67%). The majority of vehicles involved in the crashes were trains (55%), and 89% of cases occurred in urban counties.

While a majority of non-motorist entrapment incidents occur due to a lack of awareness of an oncoming train, others result from non-motorists attempting to beat the train across the tracks. For example, on July 20, 2018 a bicyclist died after being struck by a Frontrunner train in Salt Lake City. The cyclist, a 23-year-old male, was a part of a large group that meets regularly to ride. According to reports, "the group of hundreds cycled down 900 South to the railroad crossing at 600 West. One Union Pacific train passed, and about a minute later — around 11:15

p.m. — a northbound FrontRunner train came by. Unfortunately, some of the bicyclists decided to try to chance it and beat the train and get across the tracks. Most of them did. Unfortunately, a 23-year-old gentleman did not, and he is deceased (KSL, 2018)." Mitigating against this "beat the train" mentality will likely require a large educational component as suggested by Metaxatis and Sriraj (2015). Their research identified three areas in need of improvement to better mitigate incidents between non-motorists and trains. They are "a) advancing consistent standards for warning devices and treatments; b) advancing consistent approached for managing non-motorist risk; c) continuing commitment to education, engineering, and enforcement, and evaluation efforts by enabling stakeholders to provide adequate resources."

2.2.3 At-Grade Rail Crossings

According to Federal Code 49 (CFR 218.93 - Title 49 – Transportation; Subtitle B), the term "at-grade crossing" refers to "a crossing where a public highway, road, street, or private roadway, including associated sidewalks and pathways, crosses one or more railroad tracks at grade, and is identified by a U.S. DOT National Highway-Rail Grade Crossing Inventory Number, or is marked by crossbucks, stop signs, or other appropriate signage indicating the presence of an at-grade crossing (U.S. Code, 2015)."

The Federal Railroad Administration (FRA) maintains a list of all public and private roadway/railroad crossings in the United States. It also provides information about crashes involving railroads. Additionally, UDOT maintains its own regulations for at-grade crossings. Due to the complexity that these types of crossing create, UDOT has a number of specific regulations and requirements regarding at-grade crossings. For example, UDOT typically requires the closure of two existing at-grade crossings before a new one can be established. If the proposed new crossing location crosses a Union Pacific (UP) line, UP requires the closure of 3 existing at-grade crossings before the new one is approved (UDOT, 2016).

Under Utah State rules, no access is granted onto a roadway within 250 feet of a railroad track without prior approval of UDOT. If a property has a driveway onto a road that is closer than 250 feet to any tracks, the property owner must work with UDOT to apply for an exemption (UDOT, 2016). Maintenance near rail crossings is also a complicated issue and falls between the owner of the road and the owner of the tracks. "The approach to within two feet of the tracks is the responsibility of the road owner. Everything within two feet of the tracks is the responsibility of the railroad owner (UDOT, 2016)." If the road is a State highway, then UDOT is responsible for maintenance. Otherwise, the city or county is responsible for repair. There are several railroad companies operating within the state that own crossings and are responsible for their maintenance.

2.2.4 Traffic Control at At-grade Rail Crossings

There are two categories of devices used for reducing the probability of crashes occurring at the grade crossings - active and passive devices (Jang, 2005). Active devices include crossing arms, flashing light signals, and audible alerts, whereas passive devices include signage, pavement markings, and other barriers or path delineators.

The UDOT Pedestrian Grade Crossing Manual (UDOT, 2013) identifies the following as best practices and design elements:

Passive Devices

- Detectable Warning Surface (DWS)- Consists of truncated domes and assists visually impaired individuals with identifying the beginning and end of a hazard area and indicating a safe place to wait.
- LOOK Sign- The MUTCD standard LOOK sign encouraging pedestrians to look both ways prior to entering the crossing. This sign can be placed near a DWS to further enhance safety.
- STOP Pavement Markings- Is used in semi-exclusive alignments and may be coupled with a DWS to remind pedestrians to stop outside the "dynamic envelope" of the train and wait until the train clears the crossing.
- Pathway Delineation- All pavement markings, colors and textures that guide a pedestrian through a crossing. It provides a clear path for pedestrians to efficiently navigate a grade crossing.
- Channelization- Directs pedestrians to the appropriate crossing location using paint or physical devices such as fences, landscaping, or other physical obstacles.

- Barriers- Can be used within a channelized area to direct and slow pedestrian traffic. These are especially useful in areas with large pedestrian volumes. They should be placed to direct a pedestrian's line of sight toward oncoming trains, reminding individuals to look both ways before crossing the tracks.
- Swing Gates- Movable barriers that pedestrians and other non-motorists must open manually. The MUTCD requires the gates to open away from the tracks, requiring a user to pull open to enter the crossing and push to exit the crossing. These devices can be precarious for individuals with mobility issues, such as wheelchair users. Therefore, care should be taken when selecting appropriate locations for swing gates.

Active Devices

- Audible Devices- FRA regulates the use of audible devices, including bells, horns, and synthesized tones that are placed on the train and/or at crossing locations. These devices provide supplemental warning to motorists, pedestrians and cyclists. These are required at all public grade crossings except those located within a defined quiet zone.
- Flashing-Light Signals- These signals indicate the presence of an oncoming train and are commonly used to warn motorists and non-motorists at highway-rail grade crossings. Flashing signals with a crossbuck sign and an audible device are required at pedestrian and bicycle crossings where an engineering study has determined that the sight distance is not sufficient for pedestrians and bicyclists to complete their crossing prior to the arrival of a train. Pedestrian crossings located greater than 25 feet from a highway-rail crossing must provide their own crossing control.
- Blank-Out Signs- Train-activated warning signs that convey specific messages to crossing users when a train is approaching. They are often used at crossings to indicate prohibited maneuvers to vehicles. Blank out signs are required where there are sight distance restrictions and multiple tracks in order to notify pedestrians of the approach of the train.
- Automatic Gates- When flashing-light assemblies and audible devices do not provide sufficient notice, automatic pedestrian gates should be considered. They should only be used in rare circumstances where pedestrian safety concerns cannot be mitigated in any other way.

Skewed crossings are an additional concern for non-motorists as they tend to be longer than perpendicular crossings and require longer crossing times. They are also dangerous for cyclists and those with disabilities as bicycle and wheelchair wheels can get caught in the railway flanges. Warning times should be lengthened to accommodate the additional crossing time, and additional safety precautions should be taken. A typical signal provides a 20 second warning time. Crossings greater than 80 feet (20 seconds at a 4 feet per second walking rate) should provide additional accommodation for pedestrians crossing (UDOT, 2013).

Table 2 identifies UDOT's standard pedestrian safety treatments given the environmental conditions of the crossing location. Additional safety treatments may be appropriate based on specific site characteristics.

Table 2. Standard Safety Treatments

Safety Treatment	**Urban Crossings**		**Rural Crossings**
	Semi-Exclusive Alignments	Street-Running Alignments	
Crossbuck Assembly	●		●
Detectable Warning Surface	●	●	●
LOOK Sign (R15-8)	●	●	
"STOP" Pavement Marking	●		
Pathway Delineation	●	●	●

*Source: UDOT (2013)

At-Grade Crossing Safety Programs

While the FRA does not provide direct regulation or guidance regarding local crossings, they do provide general oversight and funding for repairs and elimination of hazards (FHWA, 2018). The Railway-Highway Crossing Program provides funds for the elimination of hazards at railway-highway crossings and has been correlated with a significant decrease in fatalities at such crossings. From the Program's inception in 1987 through 2014, for which most recent data is available, fatalities at these crossings have decreased by 57 percent. The overall reductions in fatalities come despite an increase in the vehicle miles traveled on roadways and an increase in the passenger and freight traffic on the railways.

The 2015 Fixing America's Surface Transportation (FAST) Act provides direct funding for railway-highway crossing improvements from the Highway Safety Improvement Program (HSIP). “Each State is required to conduct and maintain a survey of all highways to identify railroad crossings that may require separation, relocation, or protective devices, and establish and implement a schedule of projects. At a minimum, this schedule is to provide signs for all railway-highway crossings (FHWA, 2018).”

Operation Lifesaver is a non-profit, education program that was created in 1972. The program seeks to “end collisions, deaths and injuries at highway-rail grade crossing and on and around railroad tracks (Operation Lifesaver, 2016)”. Operation Lifesaver programs are co-sponsored by government agencies, highway safety organizations, the nation’s railroads, and other safety partners. The organization trains volunteers to speak to school groups, driver education classes, community audiences, professional driver groups, law enforcement officers, and emergency responders.

2.3 Study Methods

This research employed a number of statistical analysis methods, including summary statistics and multinomial regression models, to describe trends in the data as well as make predictions regarding correlation and causality between variables. Each method is described in detail below and was selected based on its appropriateness for use with study-specific data and the research questions and hypotheses.

2.3.1 Summary Statistics

Summary statistics are used to provide a quick and simple description of the data without any predictive component or significance testing. They include mean (average), median (center point of data), mode (most frequently occurring value), minimum value, maximum value, value range, standard deviation, and frequency percentages. Summary statistics were used in this analysis to provide context for the fatal crash data, describe crash report limitations, and summarize common characteristics in fatalities, pedestrian and bicyclist fault, and day/time analysis.

2.3.2 Pearson's Chi-Square Test

A Chi-Square test is used on categorical data to compare an observed distribution to a theoretical one (measuring goodness of fit) for one or more categories. The events included must be mutually exclusive (e.g., weather cannot be clear and raining at the same time) and have a total probability of 1 (Greene, 2015).

Model:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where

χ^2 is the chi-square value
Σ is the summation sign
O is the observed frequency
E is the expected frequency

2.3.3 Maximum Likelihood Regression

Maximum Likelihood Regression is used to predict a nominal dependent variable given one or more independent variables. It is sometimes considered an extension of binomial logistic regression to allow for a dependent variable with more than two categories. As with other types of regression, multinomial logistic regression can have nominal and/or continuous independent variables and can have interactions between independent variables to predict the dependent variable (Greene, 2015). Dependent variables with M categories require the calculation of M-1 equations, one for each category relative to the reference category, to describe the relationship between the dependent and independent variables.

Model:

If the first category is the reference, then, for M=2,…,M,

$$\ln \frac{P(Yi = m)}{P(Yi = 1)} = \alpha_m + \sum_{k=1}^{K} \beta_{mk} X_{ik} = Z_{mi}$$

Hence, for each case, there will be M-1 predicted log odds, one for each category relative to the reference category. When there are more than 2 groups, for m=2,…,M,

$$P(Y_i = m) = \frac{exp(Z_{mi})}{1 + \sum_{h=2}^{M} exp(Z_{hi})}$$

For the reference category,

$$P(Y_i = 1) = \frac{1}{1 + \sum_{h=2}^{M} exp(Z_{hi})}$$

Assumptions:

- The dependent variable is measured at the nominal level
- There are one or more independent variables that are continuous, ordinal, or nominal (including dichotomous variables)
- Observations are independent and have mutually exclusive and exhaustive categories
- There is no multicollinearity
- There is a linear relationship between any continuous independent variable and the logit transformation of the dependent variable
- There are no outliers, high leverage values, or highly influential points

When interpreting a maximum likelihood regression model, one of the response categories is used as a baseline or reference cell, log-odds are then calculated for all other categories relative to this baseline, and then the log-odds become a linear function of the predictors.

2.3.4 Poisson Loglinear Regression

Poisson regression is similar to regular multiple regression analysis except that the dependent (Y) variable is a count that is assumed to follow the Poisson distribution. For this research it is used to examine the number of non-motorists who exhibit risky behavior while crossing the rail line. Both numeric and categorical independent variables may be specified in a similar manner to that of the Multiple Regression procedure described above. The Poisson Regression procedure provides an analysis of deviance table, log likelihood analysis, as well as the necessary coefficient estimates and Wald tests. The Poisson distribution models the probability of *y* events (i.e. failure, death, or existence) with the formula:

$$Pr(Y = y|\mu) = \frac{e^{-\mu}\mu^{y}}{y!}(y = 0,1,2, \dots)$$

The Poisson distribution is specified with a single parameter μ. This is the mean incidence rate of a rare event per unit of exposure. Exposure may be time, space, distance, area, volume, or population size. For this research, it includes exposure to a specific treatment (e.g. audible signal, pedestrian barriers, etc.). Because exposure is often a period of time, we use the symbol *t* to represent the exposure. When no exposure value is given, it is assumed to be one.

The parameter μ may be interpreted as the risk of a new occurrence of the event during a specified exposure period, *t*. The probability of *y* events is then given by

$$Pr(Y = y|\mu, t) = \frac{e^{-\mu t}(\mu t)^{y}}{y!} (y = 0,1,2, \dots)$$

The Poisson distribution has the property that its mean and variance are equal.

In Poisson regression, we suppose that the Poisson incidence rate μ is determined by a set of *k* regressor variables (the *X's*). The expression relating these quantities is

$$\mu = t\exp(\beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k)$$

Note that often, $X_1 \equiv 1$ and β_1 is called the *intercept*. The regression coefficients $\beta_1, \beta_2, \Lambda, \beta_k$ are unknown parameters that are estimated from a set of data. Their estimates are labeled $b_1, b_2 \dots b_k$. Using this notation, the fundamental Poisson regression model for an observation *i* is written as

$$Pr(Y_i = y_i|\mu_i, t_i) = \frac{e^{-u_i t_i}(u_i t_i)^{y_i}}{y_i!}$$

Where

$$\mu_i = t_i \mu(x_i' \beta)$$

$$= t_i exp(\beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki})$$

That is, for a given set of values of the regressor variables, the outcome follows the Poisson distribution (NCSS, 2018).

2.3.5 Summary

While there are well-defined standards for vehicle rail crossing design, current national standards for pedestrian rail crossing design are less comprehensive. One of the keys to developing safer rail crossing designs is to gain a better understanding of pedestrians' behavior as they interact with crossing infrastructure. The NTSB has identified rail transit safety oversight as a "most wanted" advocacy priority. They have identified that "ineffective safety oversight is a contributing factor in many rail transit accidents.

Research has identified four major contributing factors in rail pedestrian deaths. They are lack of awareness, entrapment, risk-taking, and deliberate action. Suicides and trespassing accidents result in nearly 75% of all fatalities occurring within the American railway system. An FRA analysis determined that among individuals who committed suicide by rail, 96% were likely to have a mental disorder, 62% had a drinking problem, and 58% had a substance abuse problem.

Entrapment, when a pedestrian/cyclist cannot fully cross the rail right-of-way and becomes physically trapped on the tracks at a grade crossing, typically results from human error or lack of awareness. This can also result from distraction. Multiple studies have determined that pedestrians distracted by auditory activities, regardless of their form, are likely to be sufficiently unengaged in the act of crossing or walking along a street to perform basic tasks safely. While a majority of non-motorist entrapment incidents occur due to a lack of awareness of an oncoming train, others result from non-motorists attempting to beat the train across the tracks. Researchers have concluded that mitigating against this "beat the train" mentality will likely require a large educational component.

The FRA maintains a list of all public and private roadway/railroad crossings in the United States. It also provides information about crashes involving railroads. Additionally, UDOT maintains its own regulations for at-grade crossings. UDOT provides best practices and design elements for both active and passive methods at at-grade rail crossings, as well as standard pedestrian safety treatments given the environmental conditions of the crossing location.

This research employs a number of statistical analysis methods to describe trends in the data as well as make predictions regarding correlation between variables. Each method has been selected based on its appropriateness for study-specific data and the research questions and hypotheses. Methods include descriptive statistics, chi-square analysis, multinomial maximum likelihood regression, and Poisson loglinear regression.

3.0 DATA COLLECTION

3.1 Overview

This chapter discusses the data collected for the research and presents an overview of descriptive characteristics for each of the analysis sites. The overview includes a list of crossings selected for analysis, a summary of their site characteristics, a description of demographics surrounding these locations, and a general discussion of train frequencies and traffic volumes at the crossings.

3.2 Site Identification

Based upon spatial distribution, grade crossing type, record of safety, proximity to trails, school, and other key destinations, and contextual feedback provided by the project's technical advisory committee (TAC), 26 rail crossings were selected for inclusion in the study's sample. Table 3 shows each station along with its location (county) and transit lines serviced.

This research evaluated non-motorized access and crossing conditions surrounding ten crossings in Salt Lake County, four in Weber County, five in Davis County, and seven in Utah County. Figure 1 shows the distribution of study sites (identified with red dots) along Utah's Wasatch Front. Effort was made to ensure that a representative geographic cross section was included in the sample, and that all service lines and rail types were represented. The Sugarhouse Streetcar line was omitted due to the limited number of crossings and lack of key criteria of concern (e.g. near schools, safety concerns, etc.).

Table 3. Sample Crossing Locations

Crossing Location	County	Number of Tracks	Rail Lines*
750 West - Ogden Weber County Fairgrounds	Weber	2	Union Pacific FrontRunner
1700 South - Ogden *2 Crossings (east and west)	Weber	2	Union Pacific FrontRunner
4000 South - Roy	Weber	4	Union Pacific FrontRunner
1600 North – West Bountiful Pages Lane	Davis	3	Union Pacific FrontRunner
Hillfield Road – Layton Industrial Park Drive	Davis	3	Union Pacific FrontRunner
King Street – Layton	Davis	3	Union Pacific FrontRunner
2300 North - Sunset	Davis	3	Union Pacific FrontRunner
Main Street – North Salt Lake	Davis	5	Union Pacific FrontRunner Other**
600 West – Salt Lake City	Salt Lake	4	Union Pacific Frontrunner
300 North – Salt Lake City *(Near West High School)	Salt Lake	5	Union Pacific Frontrunner
400 North – Salt Lake City	Salt Lake	6	Union Pacific Frontrunner
Trolley Station – Salt Lake City	Salt Lake	2	Trax
2100 South – South Salt Lake	Salt Lake	2	Trax
3300 South – South Salt Lake	Salt Lake	2	Trax
300 West – Salt Lake City 2200 South, Andy Ave	Salt Lake	2	Trax
Kimballs Lane – Draper Porter Rockwell Trail	Salt Lake	2	Trax
Research Way – West Valley Redwood Junction Station	Salt Lake	2	Trax
Lester Street -West Valley Jordan River Trail Access	Salt Lake	2	Trax
Main Street – Lehi *(Near Lehi HS)	Utah	2	Union Pacific FrontRunner
200 South – American Fork	Utah	2	Union Pacific FrontRunner
400 South – Orem *(North of Orem Station)	Utah	3	Union Pacific FrontRunner
700 West – Provo	Utah	3	Union Pacific FrontRunner
Freedom Blvd – Provo 200 West	Utah	4	Union Pacific FrontRunner
Main Street – Springville	Utah	1	Union Pacific Other**
SR-147 – Spanish Fork	Utah	1	Union Pacific Other**

*Union Pacific= Freight; FrontRunner= Commuter Rail; Trax= Light Rail
**Other= Industrial/Private rail, Intercity Passenger rail

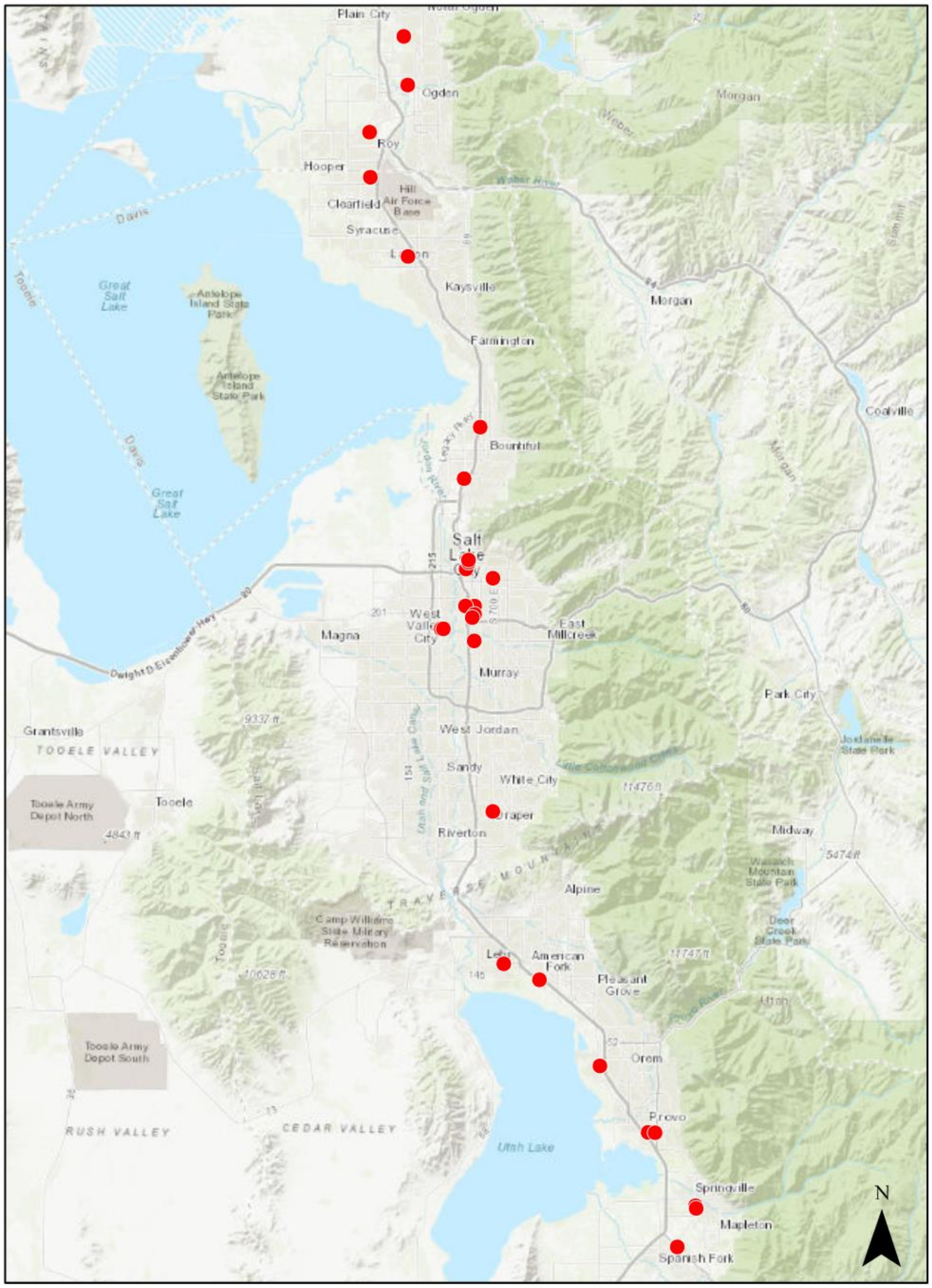

Figure 1. At-Grade Rail Crossings: Study Sample

3.2.1 Transportation System and Environment Data Collection

UDOT does not have jurisdiction over the rail lines themselves or the area immediately surrounding the tracks. However, the roadways that cross the rail lines at-grade fall under the jurisdiction of either UDOT or the local municipality/county. Therefore, while the rail authority with jurisdiction over the crossing may provide infrastructure across the tracks themselves, that infrastructure may not connect to the adjacent roadway. This research examines not only the infrastructure installed through the crossing, but also the infrastructure along the roadways crossing the tracks. Table 4 displays a complete list of characteristics types for each study site based on existing bicycle and pedestrian safety literature and prior UDOT research (Burbidge, 2012, 2014, 2015, 2017).

Table 4. Crossing Inventory Characteristics

Transportation System Characteristics	Built Environment Characteristics	Demographic Data
Number of lanes (total)	Land-Use (Res, comm, mixed)	% Population <18 (within ¼ mile)
Roadway Shoulder (y/n, width)	Building Setback (feet from curb)	% Population >65 (within ¼ mile)
Sidewalk (y/n, width)	Trail Access (y/n within ¼ mile)	% Population who bike to work
Bike Lanes (y/n)	Sound Wall	% Population who walk to work
Bike/Ped Signage	Visual Obstructions	
Non-rail pavement markings	School Zone (y/n within ¼ mile)	**Grade Crossing Characteristics**
Speed Limit		Rail signal types
On-Street Parking		Crossing distance (stop line to stop line)
Non-Residential Access Points (within 100m)		Number of Tracks
Residential Access Points (within 100m)		Non-Motorist Accommodations (y/n)
Center Median		Non-Motorized Signage (y/n)
Pavement Conditions		Non-Motorized Pavement Markings (y/n)
Roadway Maintenance		ADA Accommodation (y/n)

The following sub-sections summarize the data collected through the intersection inventories. All inventory data presented in the tables was acquired through the comprehensive site inventories and measurements unless otherwise cited.

3.3 Electronic Data Collection

Data was collected using a combination of field visits and aerial photograph analyses. Transportation system characteristics were measured using multiple methods. First, analysts measured each component using a combination of Google Earth and ArcGIS Pro with Google Licensed Imagery (GLI). GLI provides statewide aerial photography with a resolution of six inches or better with a horizontal positional accuracy to achieve or exceed one meter (C90) in most areas without significant vertical relief (Utah AGRC, 2017). The Google License provides color aerial photography, typically collected within 3 years, from the spring, summer, or fall. This level of resolution helps to ensure precision in data collection and analysis.

Preliminary built environment and station characteristic data were collected using the aerial photos described above. However, all preliminary data was confirmed through site visits (described in Section 3.4 below). Each crossing was visited in person at least twice to conduct precision confirmation measurements and to collect additional data. This ensured that any changes to the built environment of crossing areas were incorporated into the dataset and subsequent analysis. The last data that was collected for the sample sites, included characteristics of the trains traveling through the crossings. This provided data on potential exposure as it included the number of trains per day, the number of trains crossing in the day and night hours, and the maximum train speed through the area.

Key demographics (including age and journey to work data) were measured within ¼ mile of each grade crossing. Demographics have been shown to strongly correlate to non-motorized transportation. Young people (under age 18) and seniors (age 65+) are most likely to utilize walking as a mode of transportation. Both the young and old are often captive to specific modes of transportation due to legal or physical limitations. For example, individuals in Utah under age 16 cannot legally obtain a driver’s license. Likewise, seniors may lose the ability to operate an automobile as they age due to vision loss, decreased reaction times, or other degenerative conditions (Saelens, Sallis, and Frank, 2003). This makes both groups reliant on other drivers, transit or active modes such as walking or bicycling. According to the U.S. Census American Community Survey, 30.7% of Utah’s population is under age 18 and 10% is over age 65 (2016).

3.4 On-Site and Travel Behavior Data Collection

Each crossing area was visited on at least two separate occasions. The first visit was intended to confirm built environment and transportation system data previously collected electronically. The second site visit was used to evaluate user experience and monitor non-motorized access to stations.

3.4.1 Site Visits and Field Work

On-site distance measurements were taken for sidewalks, shoulder widths and crossing distances using a Rolatape measuring wheel. Building setbacks were also confirmed using both the Rolatape and a handheld laser measuring tool. A visual scan was used to confirm on-street parking and non-motorized signage, signals and infrastructure. Land-use was also validated along with transportation system characteristics (e.g. bike lanes).

The second site visit was conducted to evaluate non-motorized access to each station from the perspective of a non-motorized traveler, to count non-motorists accessing the stations, and to administer travel behavior intercept surveys to pedestrians and bicyclists. Table 11 shows the dates and times for the secondary site visits and travel behavior data collection.

Non-motorist access counts were conducted between July 31-August 30, 2018 in two-hour block increments at each crossing between approximately 7:00am and 12:00pm. The weather on all days was clear and sunny. Three locations were counted twice. The second data collection time was deemed necessary and conducted specifically to capture significant school/student traffic at certain locations once students returned for Fall term (after August 22, 2018). The schedule of on-site data collection is shown in Table 5 below.

Table 5. On-Site Data Collection Schedule

Crossing Location	Count Date	Time*
750 West - Ogden Weber County Fairgrounds	August 9, 2018	9:50-11:50
1700 South - Ogden Both Crossings	August 10, 2018	9:35-11:35
4000 South - Roy	August 8, 2018	7:30-9:30
1600 North – West Bountiful Pages Lane	August 14, 2018	8:00-10:00
Hillfield Road – Layton Industrial Park Drive	August 8, 2018	7:20-9:20
King Street – Layton	August 8, 2018	10:05-12:05pm
2300 North - Sunset	August 9, 2018	7:10-9:10
Main Street – North Salt Lake	August 7, 2018	6:55-8:55
600 West – Salt Lake City	August 7, 2018	9:05-11:05
300 North – Salt Lake City *(Near West High School)	August 14, 2018 August 30, 2018	7:30-9:30 7:00-8:00
400 North – Salt Lake City	August 7, 2018 August 14, 2018	10:00-12:00pm 10:00-12:00pm
Trolley Station – Salt Lake City	August 7, 2018	7:30-9:30
2100 South – South Salt Lake	August 9, 2018	7:00-9:00
3300 South – South Salt Lake	August 9, 2018 August 22, 2018	10:00-12:00pm 7:00-9:00
300 West – Salt Lake City 2200 South, Andy Ave	August 7, 2018	9:30-11:30
Kimballs Lane – Draper Porter Rockwell Trail	August 6, 2018	9:35-11:35
Research Way – West Valley Redwood Junction Station	August 15, 2018	7:30-9:30
Lester Street -West Valley Jordan River Trail Access	August 15, 2018	9:45-11:45
Main Street – Lehi *(Near Lehi HS)	August 3, 2018	7:50-9:50
200 South – American Fork	August 15, 2018	9:35-11:35
400 South – Orem *(North of Orem Station)	August 2, 2018	8:05-10:05
700 West – Provo	July 31, 2018	10:05-12:05pm
Freedom Blvd – Provo 200 West	July 31, 2018	7:15-9:15
Main Street – Springville	August 2, 2018	7:00-9:00
SR-147 – Spanish Fork	August 2, 2018	9:35-11:35

**All times are AM (morning) unless denoted as PM*

Project staff documented all vehicles and non-motorists who crossed the grade-crossing during the observation window. Counts were documented using the TurnCount Lite application. TurnCount Lite is a simplified version of the full TurnCount app and is intended for use by civil engineers, planning organizations, or others who do not require the complexity provided by the full TurnCount app. The application collects intersection count information with self-populated date, day and time fields. Data is entered manually using an onscreen keyboard (shown in Figure 2 below).

Figure 2. TurnCount Interface View

Vehicular traffic is counted by indicating the movement direction using the green and blue arrows, and non-motorists are counted by swiping the pedestrian icon in the direction of the crossing. When the counts were complete, the data is exported to a .csv file that date/time stamps every recorded movement. This also allowed the project team to identify complex movements, such as a pedestrian crossing the street from one side to another before navigating the rail grade crossing. While this application allowed for improved ease of data collection there was one drawback. The app did not allow for the distinction between pedestrians and cyclists. Therefore, all non-motorists were aggregated into a single non-motorist category.

Data for train frequencies was also collected from the USDOT Crossing Inventory Forms for each location (FRA, 2018d). The form specified the number of trains that cross each location in a given day. The number of day and night trains, number of passenger and freight trains, and the minimum speeds that trains travel through the crossing location.

3.5 Data Quality

The research team has high confidence in the internal and external validity of the crossing site data. As data was collected electronically and verified on site there is little likelihood that errors were made or that the data collected is a misrepresentation of actual site conditions. The only exception would be for the site in Roy. Built environment data was collected for the site and verified twice. However, when a secondary vehicle and non-motorist count was attempted, the site was under construction. This would indicate that changes (including improvements) were made to the site but were not included in the analysis. Therefore, this analysis should only be interpreted based on the conditions of the sites at the time the original data was collected.

Collecting non-motorized user counts was difficult for a number of reasons. First, at many of the busier crossings, the researchers on site could not definitively see every person who approached the crossing from every direction. This created several inherent data internal validity issues. The most obvious is the potential for under-counting or "missing" people who navigated the crossing in a larger group. The counterpart would be the possibility of over-counting. This was significantly less likely, but would include counting persons who may have approached a crossing from one direction in a crowd and then changed direction resulting in being counted twice. Pedestrians were much more likely to be under counted than cyclists as cyclists are more easily observed as distinct individuals, even in crowded circumstances.

Another drawback in collecting on-site vehicle and non-motorist counts was the limitation in collecting non-motorist characteristics. Again, this was most prevalent at sites with large groups of pedestrians. At a majority of the crossing sites, researchers were able to delineate between non-motorists to the point of noting exceptional characteristics, such as distractions, location of crossing, and obedience to signals and signage. However, at several of the busiest sites (e.g. Trolley Station, 2100 South, and 3300 South), it was nearly impossible to indicate individual characteristics. In these cases, blanket behavioral observations were made based on the behavior of the majority at any given time. When individual behavior could be observed, it was noted.

3.6 Summary

This research evaluates non-motorized access and crossing conditions surrounding at grade rail crossings. This includes ten crossings in Salt Lake County, four in Weber County, five in Davis County, and seven in Utah County. Sites were selected by the research team with input from the TAC based on including a representation of several different site types and location circumstances.

A combination of 30 specific transportation system, built-environment and other site characteristics were collected for each location. Data was collected using a combination of field visits and electronic aerial photograph analyses. Preliminary data collection utilized Google Earth and Geographic Information System (GIS) analysis tools. All data was verified and re-measured by a member of the research team during on-site visits. Demographic data for areas surrounding each crossing were collected from the U.S. Census and the American Community Survey (2016).

Each crossing area was visited on at least two separate occasions. The first visit was intended to confirm built environment and transportation system data previously collected electronically. The second site visit was used to evaluate user experience and monitor non-motorized access to stations. Researchers conducted non-motorist access counts and behavioral observations in two-hour block increments at each crossing. Motorized vehicles were also counted.

Lastly, train frequency data was collected for each sample crossing using data provided on USDOT Crossing Inventory Forms for each location (FRA, 2018d). These data included the number of trains per day, daytime/nighttime trains, and the minimum speed trains travel through the crossing.

4.0 DATA EVALUATION

4.1 Overview

This section includes analysis of all site and behavioral data. First, descriptive statistics are provided describing the road network surrounding each station and the bicycle and pedestrian components that are represented. Next, statistical methods are used to identify significant correlations between transportation characteristics, built environment characteristics, demographics, and non-motorist travel behavior.

4.2 Summary Statistics

4.2.1 Site Characteristics

A summary analysis of the sample sites determined that while there are a number of similarities among the crossings, there are also key differences. Table 6 below provides a preliminary summary of site characteristics. A majority of crossings (74%) are lower volume roadways with only two lanes and low speeds (63% under 30 mph). A majority of the roadways do provide a shoulder for non-motorists (67%), however there is a great deal of variation in the shoulder width. Most crossings have sidewalks (89%) on at least one side of the roadway, although they are typically narrow (69% less than 6 feet) and nearly 25% will not easily accommodate non-motorists with mobility issues or those in a wheelchair.

Table 6. Built Environment Characteristics

Characteristic		% of sample
Number of Travel Lanes	2	74.1
	4	11.1
	6	3.7
	7-8	11.1
Roadway Shoulder		67.0
Roadway Shoulder Width	0-4 ft	24.0
	5-8 ft	12.0
	9-10 ft	8.0
	11+ ft	20.0
Sidewalks		89.0
Sidewalk Width	4 ft	23.0
	5-6 ft	46.0
	7-8 ft	7.6
	9+ ft	11.5
Roadway Speed Limit	25	33.0
	30	30.0
	25	22.0
	40	11.0
	50	4.0
Non-Residential Access (within 100 m of crossing)	0	7.7
	1	53.8
	2-3	19.2
	4-5	7.6
	6+	11.4
Residential Access (within 100 m of crossing)	0	55.6
	1	22.2
	2-3	11.1
	4+	11.1
Building Setback (ft)	0-20	23.6
	21-40	11.8
	41-60	47.1
	61+	17.7
Land-Use	Res	29.6
	Comm	11.1
	Mixed	51.9
	Ind	7.4
Bike Lanes		78.0
Pedestrian Pavement Markings		22.0
Pedestrian Signage		34.0
On Street Parking		40.0
Center Median		29.6
Trail Access within ¼ Mile		22.2
Sound Wall		3.7
Visual Obstructions		29.6
School Zone Nearby		38.5
ADA Accommodation at Crossing		53.8

In most locations the number of access points within 100m of crossings was low. Only, 11% of locations have 4 or more residential access points. However, nearly 1 in 5 locations have four or more non-residential access points. Prior research has shown that the number of non-residential access points near intersections is positively correlated to an increase in non-motorized crashes (Burbidge, 2015).

A large majority of crossings had bike lanes (78%), and approximately half provided ADA accommodation at the crossing (53%) or on street parking (40%). Less common were pedestrian pavement markings (22%) and signage (34%), a center median (39.6%) or a sound wall (3.7%). Just over 20% of crossings were located within ¼ mile of a non-motorized trail. Nearly one in 3 locations exhibited some sort of visual obstruction which inhibited the visibility of travelers (29.6%).

4.2.2 Crossing Characteristics

In addition to simple site characteristics, a number of crossing specific characteristics were documented. As shown in Table 7 below, a large majority of crossings contained 2-3 tracks, with one notable crossing containing 6 tracks. The distance required to cross the railroad right-of-way was also measured and documented. This was included to better understand the relationship between the distance a non-motorist would be required to travel from one side of the crossing to the other and the signal headway provided at the crossing. Approximately 1/3 of crossings were less than 100 feet, 39% were between 100-200 feet, and 7.4% required traveling over 200 feet to clear the tracks. A typical able-bodied adult walks 5.5 feet per second (1.67 meters). This is equal to approximately 3.75 miles per hour (6.0 kilometers per hour). Children, seniors, and those with mobility issues walk slower, averaging just under 5 feet per second (1.5 meters) or 3.4 miles per hour (5.47 kilometers per hour) (Burbidge, 2016). A rail crossing that requires a 150-foot clearance would take between 25-30 seconds to cross, while a 200+ foot crossing could require nearly 40 seconds to clear from one side to the other. A majority of signals provide less than 30 seconds of headway time when a train is approaching. This would imply that a pedestrian who begins crossing before the signal alert may not be able to navigate to the other side of the crossing before the train reached the crossing.

Table 7. Crossing Characteristics

Characteristic		% of sample
Number of Tracks	1	7.4
	2	48.1
	3	22.2
	4	11.1
	5	7.4
	6	3.7
Pavement Condition	Poor	3.7*
	Fair	33.3
	Good	44.4
	Like New	18.5
Crossing Distance (ft)	50-100	33.3
	100-120	22.2
	121-140	22.2
	141-199	14.8
	200+	7.4

**4000 South Roy was the only site with poor quality pavement.*

Most locations (92%) provided at least basic non-motorist accommodations such as channelization, barriers, and flashing light signals, while some locations included additional safety precautions such as pathway delineation, audible devices, and blank-out signs. Only one site included swing gates on the non-motorist path and none of the included sites employed automatic gates specifically for the non-motorist path.

Table 8. Non-Motorist Accommodation (92%)

Type	%
Pathway Delineation	38.6
Channelization	67.9
Barriers	60.7
Swing Gates	3.4
Audible Devices	20.7
Flashing Light Signal	79.3
Blank-Out Signs	27.6
Automatic Gates	0.0

While a large majority of sites (85%) included some type of pedestrian signage or pavement marking, different types of signs and markings were present at each site (Table 9). Only detectable warning surfaces (DWS) were widely employed, which is likely due to ADA requirements rather than a focus on accommodations specifically for non-motorists. Other markings included pathway delineation/paint (29.6%), skewed crossing signs (18.5%), LOOK signage (48.1%), and STOP pavement markings (63%).

Table 9. Non-Motorist Signage/Pavement Markings (85%)

Type	**%**
Pathway Delineation/Paint	29.6
Skewed Crossing Sign	18.5
LOOK Sign	48.1
Detectable Warning Surface	70.4
STOP Pavement Marking	63.0

Next, the number of trains at each crossing was identified to determine potential exposure rates for non-motorists. As Table 10 shows, a majority of locations have fewer than 100 trains per day. However, some of the busiest crossings in the sample accommodate over 200 trains per day. The maximum train speeds are relatively slow (25-40 mph; 40-65 kph) for approximately one third of the sample, yet for nearly half of the crossings measured the maximum train speeds exceed 61 mph (98kph). Trains crossing at these speeds would give pedestrians very little opportunity to clear the right-of-way quickly and any collision at this speed would likely result in a fatality.

Table 10. Train Characteristics

Characteristic		**% of sample**
Trains per Day	5-25	22.2
	26-100	51.8
	101-200	18.5
	201+	11.1
Day Trains	0-50	70.4
	51-100	18.5
	101+	11.1
Night Trains	0-50	70.4
	51-100	18.5
	101+	11.1
Maximum Train Speed	25-40	33.3
	41-60	22.2
	61+	44.4

4.2.3 Demographics

Areas with higher rates of walking and biking for work trips typically also exhibit higher rates of non-motorized trips for all purposes (Audrey, Procter, and Cooper, 2014). As shown in Table 11, many of the sites considered in this analysis exhibited walking and cycling rates higher than the statewide average (shown shaded). This is likely due to the focus on Transit Oriented Development (TOD) near many of the included grade crossings (and nearby transit stations), which encourages non-motorized transportation.

Table 11. Summary of Area Demographics*

Crossing Location	% Population Under 18	% Population Over 65	% Population Bike to Work	% Population Walk to Work
750 West - Ogden Weber County Fairgrounds	36.9	3.9	2.5	0.5
1700 South - Ogden Both Crossings	36.1	11.2	1.5	5.9
4000 South - Roy	28.8	23.17	0.0	5.0
1600 North – West Bountiful Pages Lane	28.0	12.0	0.1	0.1
Hillfield Road – Layton Industrial Park Drive	33.0	7.0	0.0	0.0
King Street – Layton	33.0	7.0	0.0	0.0
2300 North - Sunset	34.2	8.3	0.0	0.0
Main Street – North Salt Lake	33.0	6.0	0.5	2.0
600 West – Salt Lake City	8.5	8.4	5.9	15.0
300 North – Salt Lake City (Near West High School)	19.1	7.3	4.8	6.2
400 North – Salt Lake City	19.1	7.3	4.8	16.0
Trolley Station – Salt Lake City	4.0	25.0	2.0	0.0
2100 South – South Salt Lake	21.0	15.0	1.3	4.0
3300 South – South Salt Lake	37.0	7.0	0.0	3.6
300 West – Salt Lake City 2200 South, Andy Ave	19.0	7.5	0.0	5.0
Kimballs Lane – Draper Porter Rockwell Trail	36.0	6.0	0.0	3.0
Research Way – West Valley Redwood Junction Station	26.4	9.3	0.0	1.8
Lester Street -West Valley Jordan River Trail Access	26.4	9.3	0.0	1.8
Main Street – Lehi (Near Lehi HS)	38.0	5.0	0.0	0.0
200 South – American Fork	34.0	9.0	0.0	4.0
400 South – Orem (North of Orem Station)	19.0	0.1	3.0	14.0
700 West – Provo	19.0	8.0	0.0	4.0
Freedom Blvd – Provo 200 West	19.0	8.0	0.0	4.0
Main Street – Springville	30.0	8.0	0.0	0.0
SR-147 – Spanish Fork	16.0	7.0	0.0	3.0
State of Utah	**30.7**	**10.0**	**0.7**	**2.40**

**Source: U.S. Census, 2016*

Several age characteristics were of note within the sample. For example, although Trolley Station exhibits a very small percentage of children (4%), the percentage of seniors within walking distance of the crossing is nearly 2.5 times the state average. Other areas with a large percentage of seniors included 4000 South-Roy and 2100 South- South Salt Lake. None of the study locations had an unexpectedly high youth population.

4.2.4 Traffic Volumes and Train Frequencies

There were very high non-motorist volumes in the more urban areas (Tolley Station-Salt Lake City, 3300 South-South Salt Lake, Research Way-West Valley City, and Freedom Boulevard-Provo), with very low non-motorist volumes in the more rural or industrial areas (1700 South-Ogden, King Street-Layton, 400 South-Orem, Main Street-Springville, and SR-147 Spanish Fork), as shown in Table 12 below.

To provide additional insight into non-motorist traffic, a ratio was calculated dividing the number of non-motorists by automobiles at a given location. The result provides a percentage ratio of traffic. For example, at the 750 West- Ogden crossing a large number of vehicles (940) were observed, however only 11 non-motorists crossed during the same time period. The ratio of non-motorists to motorists is 0.012, which equates to a 1.2% share of total traffic. This indicates that non-motorists do not make up a large percentage of the overall traffic at this site. Alternatively, at 300 North in Salt Lake City (near West High School), while 149 and 119 vehicles were observed during the two separate site visits, 55 and 73 non-motorists were observed. This site indicates that non-motorists make 21-23% of total crossings, indicating a large presence. These ratios and percentages are a simple way to quickly assess how widely the crossing is used by non-motorists and what type of exposure may result. They are also an indication of where resources may best be spent at improving non-motorist conditions.

Table 12. Vehicle and Non-Motorist Counts

Crossing Location	Vehicles	Non-Motorists	Ratio NM/Auto (%)
750 West - Ogden Weber County Fairgrounds	940	11	1.2
1700 South - Ogden Both Crossings	195	6	3.0
4000 South - Roy	854	19	2.2
1600 North – West Bountiful Pages Lane	541	28	4.9
Hillfield Road – Layton Industrial Park Drive	2,162	10	0.5
King Street – Layton	276	8	2.8
2300 North - Sunset	244	11	4.3
Main Street – North Salt Lake	250	4	1.6
600 West – Salt Lake City	356	68	16.0
300 North – Salt Lake City *Near West High School	183 264	55 73	23.1 21.7
400 North – Salt Lake City	149 119	13 13	8.0 9.8
Trolley Station – Salt Lake City	3435	419	10.9
2100 South – South Salt Lake	2,264	139	5.8
3300 South – South Salt Lake	5,491 4,695	130 112	2.3 2.3
300 West – Salt Lake City 2200 South, Andy Ave	2,045	34	1.6
Kimballs Lane – Draper Porter Rockwell Trail	1,860	28	1.5
Research Way – West Valley Redwood Junction Station	2,564	115	4.3
Lester Street -West Valley Jordan River Trail Access	151	15	9.0
Main Street – Lehi *Near Lehi HS	1,975	19	1.0
200 South – American Fork	369	11	2.9
400 South – Orem *North of Orem Station	1,002	3	0.3
700 West – Provo	189	29	13.3
Freedom Blvd – Provo 200 West	748	72	8.8
Main Street – Springville	71	6	7.8
SR-147 – Spanish Fork	274	2	0.7
Total	**31,472**	**1,459**	

Train frequencies were also considered for each location to ensure consideration of potential conflicts between non-motorists and trains. As shown in Table 13, 3300 South (South

Salt Lake) and 300 West (Salt Lake City) have the highest frequencies of trains per day resulting in the highest exposure and potential for collisions. Kimballs Lane (Draper), Research Way (West Valley City), Lester Street (West Valley City) and 2100 South (South Salt Lake) also experience very high train frequencies. 750 West (Ogden), Main Street (Springville), and SR-147 (Spanish Fork) have the lowest train frequencies with only 8 per day, all of which are freight-only. However, because of their more rural locations, the minimum speed traveled in these low-frequency areas is higher than through the urban corridors.

Table 13. Train Frequencies

Crossing Location	Trains per day	Minimum Speed*
750 West - Ogden Weber County Fairgrounds	8	79 (128)
1700 South - Ogden Both Crossings	70	25 (40)
4000 South - Roy	14	40 (64)
1600 North – West Bountiful Pages Lane	56	45 (72)
Hillfield Road – Layton Industrial Park Drive	56	79 (128)
King Street – Layton	56	79 (128)
2300 North - Sunset	56	79 (128)
Main Street – North Salt Lake	56	79 (128)
600 West – Salt Lake City	56	79 (128)
300 North – Salt Lake City -Near West High School	56	79 (128)
400 North – Salt Lake City	68	35 (56)
Trolley Station – Salt Lake City	68	55 (88)
2100 South – South Salt Lake	147	55 (88)
3300 South – South Salt Lake	427	55 (88)
300 West – Salt Lake City 2200 South, Andy Ave	293	40 (64)
Kimballs Lane – Draper Porter Rockwell Trail	159	65 (104)
Research Way – West Valley Redwood Junction Station	158	35 (56)
Lester Street -West Valley Jordan River Trail Access	159	35 (56)
Main Street – Lehi -Near Lehi HS	54	79 (128)
200 South – American Fork	56	79 (128)
400 South – Orem -North of Orem Station	56	79 (128)
700 West – Provo	9	40 (64)
Freedom Blvd – Provo 200 West	9	40 (64)
Main Street – Springville	8	50 (80)

SR-147 – Spanish Fork	8	60 (96)

**All speeds are shown in miles per hour, with kilometers per hour shown in parentheses*

4.3 Travel Behavior

As mentioned in Section 3.5 in the discussion on data quality, it was difficult to evaluate specific travel behavior patterns for all non-motorists due to the sheer volume of people at many of the rail crossings. However, when possible individual travel behavior was noted including compliance with existing infrastructure, signage and safety treatments, risky behaviors (crossing against signals, lingering on tracks, etc.), and distraction (e.g. looking at an electronic device, wearing headphones). This also included noting whether or not non-motorists were following the indicated path when crossing the tracks, and if they exhibited any other notable behaviors that may inhibit their safety at the crossing. As noted in the introduction of this report, this research sought to determine:

- What is the current level of compliance with existing non-motorized safety treatments?
- Are pedestrians and cyclists exhibiting risky behavior when navigating rail crossings?
- What route/path are non-motorists using to navigate the rail crossings?
- What other notable travel behavior characteristics are present during non-motorized at-grade rail crossings?

4.3.1 Non-Motorist Compliance

In total, 1,459 non-motorists were observed at the 26 crossing sites. Table 14 below provides a breakdown of compliance with signs, signals and pathway markings. Approximately 80% of the non-motorists observed crossed in the appropriate location and adhered to all signage and signals located at the crossing.

Table 14. Non-Motorist Compliance at Crossings

Non-Motorist Behavior	% Sample
Crossed as intended	79.2
Adhered to signs and signals	84.1
Followed approved pathways	81.2
N=1,459	

A large majority of non-motorists (84.1%) adhered to the guidance provided by existing signage and signals, including cross bucks, blank out signals, and audible devices. and did not attempt to cross when it was not safe to do so. However, nearly 20% of the non-motorists observed did not follow the approved pathway through the crossing, as described in greater detail below.

4.3.2 Risky Behaviors

Nearly 20% of the non-motorists observed in the sample exhibited at least one risky crossing behavior. These included lingering on the tracks rather than crossing quickly (4.2%), disregarding signals or signage (15.9%), crossing through gate arms once they have lowered or as they are lowering (3.7%), walking around gates or barriers (17.2%) and walking into vehicular traffic, typically to avoid existing barriers and gates (18.4%).

Table 15. Risky Behaviors

Risky Behavior	% Sample
Exhibited at least one risky behavior	18.8
Lingering on tracks	4.2
Disregarding signals or signage	15.9
Crossing through cross-arms	3.7
Walking around z-gates or barriers	17.2
Walking into vehicular traffic	18.4
N=1,459	

These risky behaviors not only impose the risk of a conflict between a train and a non-motorist when they do not comply with safety provisions, but also the potential for a conflict between a vehicle and a non-motorist when they travel into an area where they are not expected.

4.3.3 Distraction

Distractions can be incredibly dangerous near rail crossings. In recent years there has been a significant increase in conflicts between pedestrians and trains due to the pedestrian being distracted in some way (Mwakalonge, Siuhi, and White, 2015). Many non-motorists within the sample studies for tis UDOT research were notably distracted. 11.8% of those observed were distracted in at least one way, with many exhibiting multiple distractions. The most common distraction was an electronic device (e.g. cell phone, tablet, etc.), often accompanied by wearing headphones (8.6%).

Table 16. Non-Motorist Distractions

Distractions	% Sample
Distracted in any way	11.8
Using an electronic device	10.4
Wearing headphones	8.6
Socializing with others	4.9
Other distraction	2.2
N=1,459	

Approximately 5% of the non-motorists observed were socializing with others while crossing, and 2.2% exhibited some other kind of distraction (e.g. wrangling children, paying attention to other surroundings, eating, and even reading). Observational studies examining the effect of cell phone use on crossing behavior have found that the pedestrians cross more slowly when conversing on a cell phone, are less likely to look at traffic before entering the roadway, and make more unsafe crossings compared to non-distracted pedestrians (Bungum, et al, 2005). Slower than normal walking speeds can also impact safety in crossings as discussed in Section 4.2.2. If a pedestrian has a sizable distance to cross in order to clear the tracks, they may not have enough time to safely clear the right-of-way. This is true even if they are walking with awareness with no distractions.

4.4 Environment and Behavior

To understand the relationship between the crossing environment and non-motorist behavior, several statistical models were run. Prior to analysis, however, the number of non-motorists exhibiting specific behaviors was transformed into a ratio (occurrences/total non-motorists) to provide a more accurate description of sample behavior and allow for direct comparison between sites. Because these variables are included as a ratio, they are input in each model described below as an elasticity rather than a precise count. This improves accuracy and results in a more robust estimation model. Initially all models included demographics and train frequency as controls. However, these variables showed no significant correlation to non-motorist behavior and were therefore omitted from the final iterations of the models.

4.4.1 Crossing Characteristics and Behavior

Several models were run to determine the impact that the built environment had on non-motorist behavior. Maximum likelihood main effects regression models were used with parameters set to remove variables from the model that were not significant on their own, and controlling for covariation.

The first model examined the relationship between the built-environment and non-motorist compliance. In other words, it looked at whether non-motorists navigated the crossing in the manner and along the pathway intended by engineering or design. For example, if a pedestrian walked into the roadway to avoid a z-gate, they would be identified as non-compliant. In some cases, there was no infrastructure for pedestrians on one side of a crossing. In those cases, individuals were not deemed non-compliant for walking on the shoulder. As shown in Table 17, none of the built-environment variables were significantly correlated to non-motorist compliance.

Table 17. Built Environment and Non-Motorist Compliance

Variable	Beta	*t*	Sig.
-Constant-	*0.330*	*1.025*	*0.381*
Number of Travel Lanes	-0.019	-0.236	0.829
Sidewalk	0.286	0.544	0.624
Bike lanes	-0.066	-0.296	0.787
Non-Residential Access (100m)	-0.098	1.079	0.360
Residential Access (100m)	0.014	0.158	0.884
Trail Access (1/4 mile)	-0.259	-1.272	0.293
Sound Wall	1.047	2.302	0.105
Visual Obstruction	-0.233	-0.748	0.509
Building Setback	0.006	1.193	0.319
School Zone nearby	-0.115	-0.300	0.784
ADA Accommodation	-0.447	-1.080	0.359
R Square = 0.674			

A second model assessed the correlations between the built-environment and non-motorists exhibiting risky behaviors (e.g. lingering on the tracks, walking through lowered crossing gates). The R-square value for this model was 0.925, which signifies a very strong model fit. This indicates that over 90% of the variation in non-motorist behavior was accounted for by variation in the modeled covariates. The only variable that was significantly correlated to the percentage of non-motorists exhibiting risky behavior was the presence of a visual obstruction (Table 18). The presence of a visual obstruction was significantly correlated to approximately 22% more non-motorists exhibiting risky behavior. It is possible that when a visual obstruction is present, it inhibits a non-motorist's ability to assess risk. This could encourage risky behavior because non-motorists cannot see the train coming and fail to trust the signals/signage that are in place. The presence of a sound wall was nearly significant, likely for the same reason.

Table 18. Built Environment and Risky Behavior

Variable	Beta	*t*	Sig.
-Constant-	*0.266*	*4.341*	*0.023*
Number of Travel Lanes	0.016	1.097	0.353
Sidewalk	-0.016	-1.590	0.210
Bike lanes	0.055	1.302	0.284
Non-Residential Access (100m)	-0.0335	-1.986	0.141
Residential Access (100m)	0.020	1.183	0.322
Trail Access (1/4 mile)	0.083	2.133	0.123
Sound Wall	-0.247	-2.840	0.066
Visual Obstruction	0.221	3.725	0.034
Building Setback	-0.002	-2.223	0.113
School Zone nearby	0.006	0.079	0.942
ADA Accommodation	0.004	0.051	0.962
R Square = 0.925			

When modeling non-motorist distraction, the analysis determined that several environmental characteristics were strongly correlated to behavior. As shown in Table 19 below, the number of travel lanes, the presence of a bike lane, visual obstructions, a school zone near the crossing, and the presence of ADA accommodation were significantly negatively correlated to non-motorist distraction.

Table 19. Built Environment and Non-Motorist Distraction

Variable	Beta	*t*	Sig.
-Constant-	*0.242*	*2.897*	*0.063*
Number of Travel Lanes	-0.076	-5.504	0.012
Sidewalk	0.344	3.697	0.034
Bike lanes	-0.179	-4.534	0.020
Non-Residential Access (100m)	0.040	2.475	0.090
Residential Access (100m)	-0.008	-0.508	0.646

Trail Access (1/4 mile)	-0.051	-1.424	0.250
Sound Wall	0.073	0.904	0.433
Visual Obstruction	-0.332	-6.032	0.009
Building Setback	0.005	4.988	0.015
School Zone nearby	-0.343	-5.059	0.015
ADA Accommodation	-0.314	-4.290	0.023
R Square=0.959			

Each additional travel lane on the roadway at the crossing was significantly correlated to approximately 7.6% fewer distracted non-motorists at that location. The presence of bike lanes was significantly correlated to 18% fewer distracted persons. Visual obstructions, a school zone nearby and the presence of ADA accommodation were each significantly correlated to over 30% fewer distracted non-motorists. The presence of sidewalks and the building setback (in feet) were significantly correlated to more distracted non-motorists.

There could be several reasons for this. First, as the number of lanes increases (including bike lanes), the roadway environment becomes more complex. This may subconsciously require non-motorists to pay better attention to their surroundings resulting in fewer who appear distracted. Similarly, the presence of a visual obstruction would require non-motorists to pay better attention to their environment near a rail crossing. Alternatively, the presence of a sidewalk may instill a sense of false security among non-motorists who feel "safe" on the sidewalk and in turn pay less attention to the environment around them. The presence of a school zone and ADA accommodation may display built in bias against distraction. For example, children walking to school near a rail crossing may be accompanied by a guardian, or a crossing guard may be present to assist in navigating the crossing (as was the case at one site) which would encourage the children to pay attention. Likewise, the ADA accommodations at crossings (e.g. z-gates, half dome ramps) may increase focus or awareness which would result in fewer distracted individuals. Again, the R-square value for this model was 0.959 indicating a very strong model fit.

Three additional models were run to identify the impact of crossing distance (length and number of tracks), pavement conditions and maintenance conditions on non-motorist behavior. However, none of the covariates included in the model iterations were significant, so the outputs have been intentionally omitted from this report.

4.4.2 Non-Motorist Accommodations and Behavior

The second area evaluated in this analysis focused on the impact that existing non-motorist accommodations at each crossing might have on non-motorist travel behavior. There were two components to this evaluation. The first included general accommodations including: pathway delineation, channelization (e.g. z-gates), barriers, swing gates, audible devices, flashing light signals, and blank-out signs. A maximum-likelihood regression model with ratio elasticities, to control for sample percentages and representation bias, was employed to identify correlations between existing non-motorist accommodations and the level of non-motorist compliance at each crossing location. The analysis found that none of the accommodations were significantly correlated to compliance within the sample (Table 20). Audible signals were nearly significant with 94% confidence of a negative relationship (where audible signals were present there was less compliance by non-motorists).

Table 20. Non-Motorist Accommodation and Compliance

Variable	Beta	*t*	Sig.
-Constant-	*0.632*	*5.577*	*0.000*
Pathway Delineation	-0.060	-0.555	0.586
Channelization	0.181	1.265	0.221
Barriers	0.019	0.133	0.896
Swing Gates	0.125	0.489	0.631
Audible Devices	-0.246	-1.984	0.062
Flashing Light Signals	-0.005	-0.036	0.972
Blank-out Signs	-0.091	-0.761	0.456
R Square = 0.287			

Next a Poisson Loglinear regression model using main effects and a scale parameter method (evaluating each site against itself) was employed to identify correlations between non-motorist accommodations and observed risky behaviors. This was done because of the distribution of the dependent variable, and the low number of observed individuals who exhibited risky behavior. The total number of pedestrians crossing at leach location was included to control for volumes. As shown in Table 21, channelization, barriers, flashing light signals, and blank-out signs were all statistically significant variables in the model.

The absence of barriers and flashing light signals was significantly correlated to more non-motorists exhibiting risky behavior. This result is intuitive as barriers and light signals are considered an aid to help deter individuals from performing risky behaviors. Barriers keep individuals off the tracks in unsafe areas and flashing light signals inform non-motorists that a train is coming and they should stay off the tracks.

The absence of channelization and blank-out signs was significantly correlated to fewer risky behaviors among non-motorists. This can be partially explained from qualitative data gathered during the project. When the project team was on-site collecting behavioral data for this analysis they witnessed many individuals traveling around the channelization infrastructure, particularly cyclists and people pushing strollers. Many of these individuals, seeing the data collection team taking notes, commented that they wished the channelization would be removed, because it made it much more difficult to navigate the crossing. A majority of these people exhibited risky behaviors (e.g. traveling in the roadway, ignoring signage, traveling around z-gates) to avoid the channelization.

Table 21. Non-Motorist Accommodation and Risky Behavior

Variable*	Beta	*95% Confidence Interval*		Sig.
		Lower	Upper	
-Intercept-	*-23.727*	*-24.397*	*-23.056*	*0.000*
Pathway Delineation	0.451	-0.039	0.941	0.071
Channelization	-1.366	-2.030	-0.702	0.000
Barriers	1.214	0.540	1.889	0.000
Swing Gates**	25.470	-	-	-
Audible Devices	-0.111	-0.669	0.447	0.697
Flashing Light Signals	0.551	1.087	4.060	0.044
Blank-out Signs	-0.969	-1.513	-0.425	0.000
Chi- Square = 44.908				0.000

**Results show covariates set to 0 (no) to avoid redundancy.*
***Hessian Matrix singularity- last iteration shown (only one site had swing gates)*

Additionally, a qualitative observation suggested that many of the non-motorists did not understand the blank-out signs, what they are, and what information they convey. Because they are not easily understood this may lead to more non-motorists exhibiting risky behavior when they are present, as they are unsure of what they should be doing.

Lastly a maximum likelihood regression model examined correlations between non-motorist accommodations and distractions while crossing. Again, ratio elasticities were employed to control for sample percentages and representation bias. As shown in Table 22, none of the non-motorist accommodations were significantly correlated to non-motorist distraction at the crossing. This suggests that none of the accommodations are effective at increasing awareness or reducing distraction among non-motorists.

Table 22. Non-Motorist Accommodation and Distraction

Variable	Beta	*t*	Sig.
-Constant-	*204*	*2.994*	*0.007*
Pathway Delineation	-0.110	-1.682	0.109
Channelization	0.006	0.066	0.948
Barriers	0.018	0.213	0.834
Swing Gates	-0.137	-0.889	0.385
Audible Devices	-0.051	-0.686	0.501
Flashing Light Signals	0.061	0.762	0.455
Blank-out Signs	-0.056	-0.783	0.443
R Square = 0.216			

4.4.3 Pavement Markings Accommodations and Behavior

One final analysis examined the relationship between non-motorist behavior and informational pavement markings at each crossing. First a maximum-likelihood regression model with ratio elasticities was employed to determine if a relationship exists between pavement markings and non-motorist compliance. Results are shown in Table 23.

Table 23. Crossing Pavement Markings and Non-Motorist Compliance

Variable	Beta	*t*	Sig.
-Constant-	*0.752*	*8.114*	*0.000*
Pathway Delineation (paint)	0.089	0.788	0.439
Skewed Crossing Sign	-0.120	-1.114	0.278
LOOK Sign	0.034	0.346	0.733
Detectable Warning Surface	-0.231	-2.105	0.048
STOP Pavement Marking	0.093	0.990	0.333
R Square = 0.208			

The only characteristic that was significantly correlated to behavior was the presence of a detectable warning surface. Crossings that had a detectable warning surface (DWS) in the non-motorist area of a crossing exhibited 23% fewer pedestrians crossing in compliance. Initially it was hypothesized that this may be a case of collinearity and that a latent variable that is typically present with DWS (e.g. channelization or ADA accommodation) may be the underlying culprit. However, when the model was rerun including both variables as controls the DWS became more significantly correlated (*sig.*= 0.021) to compliant behavior.

Next, a Poisson Loglinear regression model using main effects and a scale parameter method (evaluating each site against itself) was employed to identify correlations between non-motorist pavement markings and observed risky behaviors (Table 24). The model included the total number of pedestrians at each crossing to control for volumes, rather than using a computed elasticity (as was used in the other regression models).

Table 24. Crossing Pavement Markings and Risky Behavior

Variable*	**Beta**	***95% Confidence Interval***		**Sig.**
		Lower	**Upper**	
-Intercept-	*0.316*	*-0.448*	*1.081*	*0.417*
Pathway Delineation (paint)	0.473	-0.022	0.967	0.061
Skewed Crossing Sign	0.118	-0.431	0.668	0.673
LOOK Sign	0.420	-0.131	0.970	0.135
Detectable Warning Surface	-2.685	-3.705	-1.666	0.000
STOP Pavement Marking	0.478	-0.077	1.304	0.092
Chi- Square = 99.377				0.000

**Results show covariates set to 0 (no) to avoid redundancy.*

Results show that DWS was once again the only pavement marking correlated to non-motorist behavior at the crossings in the sample. The absence of DWS at a crossing was significantly correlated to a decrease in risky non-motorist behavior. In order to better understand this finding, research staff performed two short (45-minute) follow-up visits to crossings included in the sample.

Figure 3. Detectable Warning Surface and STOP Pavement Marking

A qualitative observational analysis revealed that a large majority of able-bodied pedestrians actually try to avoid the raised pavement of a DWS (shown in Figure 3 above), walking to one side or another, or stepping over it completely. It is uncertain why this occurs or if it is consciously done, but even individuals who stayed in the appropriate right-of-way seemed to veer to one side of the half-domes or another.

Lastly a maximum likelihood regression was run to examine the relationship between pavement markings and pedestrian distraction. The hypothesis of this research is that distraction and pavement markings are not likely to be correlated, as distracted pedestrians are unlikely to pay attention to pavement markings and the pavement markings are less likely than audible warnings or infrastructure-based methods to reduce distraction and increase awareness. The model confirmed this hypothesis. The presence of non-motorist pavement markings was not significantly correlated to non-motorist distraction in any way (Table 25).

Table 25. Crossing Pavement Markings and Distraction

Variable	Beta	*t*	Sig.
-Constant-	*0.272*	*5.473*	*0.000*
Pathway Delineation (paint)	-0.075	-1.230	0.232
Skewed Crossing Sign	-0.114	-1.972	0.062
LOOK Sign	0.013	-1.972	0.062
Detectable Warning Surface	-0.081	-1.377	0.183
STOP Pavement Marking	0.030	0.604	0.552
R Square = 0.301			

4.5 Summary

Conditions at 26 sample crossing sites were described. A summary of site characteristics was provided including detailed analytics on the built environment surrounding each crossing location. Additionally, specific crossing characteristics were described including pavement and maintenance conditions, signage, signals and pavement markings. Local demographics were highlighted, such as walk and bike to work percentages and percentage of the population under age 18 and over age 65. Traffic volumes and specific train characteristics (number of trains, type of service, speeds) were described, and traffic volumes for both motorized and non-motorized vehicles were provided for each sample location.

The analysis focused specifically on travel behavior and how it is correlated to the crossing environment. Three focus areas were evaluated: non-motorist compliance, risky behaviors, and distraction while crossing. Each was correlated to characteristics of the built environment, non-motorist accommodations at the crossing, and non-motorist informational pavement markings.

5.0 CONCLUSIONS

5.1 Summary

This research evaluates non-motorized access and crossing conditions surrounding a sample of 26 at-grade rail crossings. Using a combination of electronic on-site data collection, a profile was developed for each crossing. Additionally, travel behavior data was gathered for all non-motorists who crossed at each location during a 2-hour observation window. Using a combination of Maximum-Likelihood and Poisson Loglinear Regression Models, behavioral data was correlated to site data to determine: the current level of compliance with existing non-motorized safety treatments; risky behaviors exhibited by non-motorists at crossings; the role distraction plays in non-motorist behavior at crossing; and other notable travel behavior characteristics present during non-motorized rail crossings.

5.2 Findings

Several environmental and crossing characteristics were correlated to travel behavior at crossings. In order to ensure that the analysis provided was robust and comprehensive, a large number of additional variables were included in various iterations of each model to ensure that latent confounding variables did not skew the analysis and that collinearity was reduced or eliminated. For example, while not discussed in detail in the analysis section, crossing distance (length and number of tracks), pavement conditions and maintenance conditions were initially included in all models evaluating non-motorist behavior. However, none of those covariates were significant so they were removed from later model iterations and final outputs.

5.2.1 Non-Motorist Compliance

The first goal of this research was to determine the level of compliance non-motorists had at crossings. This refers to the degree to which non-motorists travel and cross where they are intended to and comply with the engineering and signals/signage that have been put in place to promote maximum safety. This analysis found that nearly 20% of the non-motorists observed did not follow the approved pathway through the crossing. A robust statistical analysis found that none of the built-environment variables or non-motorist accommodations were significantly correlated to non-motorist compliance. The only characteristic that was significantly correlated to behavior was the presence of a detectable warning surface. Crossings with a detectable warning surface (DWS) in the non-motorist area of a crossing were associated with 23% fewer pedestrians crossing in compliance. While this does not definitively mean that the presence of DWS causes a reduction in compliance, there is a relationship between the two that should be further investigated.

5.2.2 Risky Behavior

The second goal of the research was to determine if non-motorists are exhibiting risky behaviors at crossings, and if so, what may contribute to these risky behaviors. Nearly 20% of the non-motorists observed in the sample exhibited at least one risky crossing behavior. These included lingering on the tracks rather than crossing quickly (4.2%), disregarding signals or signage (15.9%), crossing through crossing arms once they have lowered or as they are lowering (3.7%), walking around gates or barriers (17.2%) and walking into vehicular traffic, typically to avoid existing barriers and gates (18.4%).

Regression analysis determined that the presence of a visual obstruction was significantly correlated to approximately 22% more non-motorists exhibiting risky behavior. The absence of barriers and flashing light signals was significantly correlated to more non-motorists exhibiting risky behavior, while the absence of channelization, blank-out signs, and detectable warning surfaces (DWS) was significantly correlated to fewer risky behaviors among non-motorists.

5.2.3 Non-Motorist Distraction

The final goal of this research was to determine the role that distraction plays in non-motorist behavior and safety at crossings. Many non-motorists within the sample were notably distracted. Approximately 12% of those observed were distracted in at least one way, with many exhibiting multiple distractions. The most common distraction was an electronic device (e.g. cell phone, tablet, etc.) often accompanied by wearing headphones (8.6%). Approximately 5% of the non-motorists observed were socializing with others while crossing, and 2.2% exhibited some other kind of distraction (e.g. wrangling children, paying attention to other surroundings, eating, and even reading).

Regression analysis found that the number of travel lanes, the presence of a bike lane, visual obstructions, a school zone near the crossing, and the presence of ADA accommodation were significantly negatively correlated to non-motorist distraction. Because these add to the complexity of the environment they may encourage non-motorists to pay better attention while crossing. It is notable that neither the presence of non-motorist accommodations or pavement markings were significantly correlated to non-motorist distraction at the crossing.

5.3 Limitations and Challenges

Within the design and scope of this study every effort was made to create a high-quality project that would aptly address the research questions. However, regardless of the care taken, every research project exhibits limitations and challenges. The first major limitation in this research included constraints on the scope. Due to the timeframe and budget, the number of sites that could be evaluated was limited. To increase the external validity of the results a secondary follow-up would need to include a larger number of sites. Concomitantly, it would be beneficial to have larger observational time frames. A certain degree of data control was built into this project by ensuring that all behavioral data was collected during the same timeframe and window. However, the analysis would benefit from a larger sample of non-motorists over a greater time frame and under different conditions (weather, lighting, time of day, seasons, etc.).

The second limitation was revealed during the data collection phase. While many of the sites lent themselves nicely to collecting crossing data on a steady stream of non-motorists that were easily identifiable, if was very difficult to delineate pedestrian behavior at the locations with a larger number of non-motorists. There is not an easy solution to remedy this, because increasing the number of observers may result in double counting non-motorists. The best solution may include using video surveillance of each site which would allow the project staff to pause or go through each crossing in slow motion to ensure that each non-motorist was counted and evaluated appropriately. It would also allow for an outside opinion or secondary observation where there was uncertainty on one point or another. This would increase the data quality, but would also increase the labor (and cost) involved in collecting the observational data.

Lastly, while observational data was able to classify non-motorist behavior as it occurred, it did not provide any understanding behind why people made the decisions that they did. This is one ongoing drawback of observational data collection. Researchers can see what is happening, but may only make statistical inferences to attempt to identify why it is happening. This could be addressed in a follow-up study by pairing the observational data with an intercept survey of some kind which would observe a non-motorist crossing and then stop them to ask several questions regarding their intent and understanding. For example, distracted non-motorists could be asked their opinion on how using their electronic device might impact their safety (or if they care). Other questions could include an inquiry into what the different informational signs mean and how non-motorists are supposed to behave at rail crossings. There are inherent drawbacks in intercept surveys as well but they could add depth and breadth to a study of this type in the future.

6.0 RECOMMENDATIONS

After a thorough review of the data analysis and findings the TAC met to discuss recommendations to improve future non-motorist safety at at-grade crossings. The following seven recommendations have been identified:

1. While the presence of DWS was found to increase non-compliance at crossings and encourage pedestrians to exhibit unsafe behavior, they are an ADA requirement. Therefore, UDOT and UTA should focus on an educational campaign that explains to the public why each safety component is there (DWS, blank out signs, z-gates, etc.) and what its function is. Additional research should be conducted to determine why people avoid these surfaces and what other design options may potentially increase compliance.

2. Visual obstructions were correlated to an increase in risky behaviors. State agencies have long recognized that sight lines are critical for both train operators and non-motorists to be aware of risk and when a train is approaching. All grade crossings should be reviewed to determine how sight lines can be improved and visual obstructions can be removed.

3. Barriers (both fencing and ground treatments) are effective at keeping pedestrians within the preferred crossing right-of-way. The TAC recommends their continued implementation at crossings.

4. While z-gates are correlated to more risky non-motorist behaviors than are present in locations without them, the TAC is hesitant to recommend their removal as removing them may encourage other risky behaviors. Therefore, additional research should be conducted to determine how non-motorist behavior may change if z-gates were removed from a sample of crossings.

5. The TAC determined that blank out signs are not well understood by the public and may provide too much headway time. This is likely to confuse non-motorists and lead to risky

behaviors. Additional investigation is recommended in addition to education regarding what these signs are and what information they convey.

6. As Operation Lifesaver recommendations change each year and can be amended, the TAC recommends incorporating the findings from this report into that program and using Operation Lifesaver as an avenue to provide additional education on signage, signals and safety treatments.

7. Lastly, UDOT and UTA should avoid over engineering locations that are already complex. These include sites with a large number of lanes, bike lanes, school zones, and multiple ADA accommodations. This research determined that these complex areas actually serve to heighten awareness among non-motorists and discourage distraction. Therefore, these locations are less likely to require a large number of additional safety treatments.

REFERENCES

Audrey, S., S. Procter, and A.R. Cooper. (2014). *The International Journal of Behavioral Nutrition and Physical Activity*. 11(37).

Australia Transport Safety Bureau. (2003a). *Level Crossing Accident Fatalities*. Canberra: Australian Transport Safety Bureau.

Australia Transport Safety Bureau. (2003b). *Australian Railway Accident Fatalities - latest data*. Canberra: Australian Transport Safety Bureau.

Berman, A., R. Sundararaman, A. Price, K. Marhsall, M. Martino, A. Doucette, S. Chase, and S. Gabree. (2013). Defining Characteristics of Intentional Fatalities on Railway Rights-Of-Way in the United States, 2007-2010.

Bungum, T.J., C. Day, L.J. Henry. (2005). The association of distraction and caution displayed by pedestrians at a lighted crosswalk. *Journal of Community Health*, 30 (4), pp. 269-279.

Burbidge, S.K. (2017). Risk Assessment of Non-Motorized access to Rail Transit Stations. Salt Lake City: Utah Department of Transportation.

Burbidge, S.K. (2016). Measuring Pedestrian Exposure and Risk in High-Risk Areas. Salt Lake City: Utah Department of Transportation.

Burbidge, S.K. (2015). Identifying Characteristics of High-Risk Intersections for Pedestrians and Cyclists: Phase 3. Salt Lake City: Utah Department of Transportation.

Burbidge, S.K. (2014). Identifying Characteristics of High-Risk Intersections for Pedestrians and Cyclists: Phase 2. UT-15.11. Salt Lake City: Utah Department of Transportation.

Burbidge, S.K. (2012). Identifying Characteristics of High-Risk Intersections for Pedestrians and Cyclists. UT11.305, 12-0947. Salt Lake City: Utah Department of Transportation.

Cina, S., Koelpin, J., C. Nichols, and S. Conradi. (1994). A Decade of Train-Pedestrian Fatalities: The Charleston Experience. *Journal of Forensic Sciences*, 39(3), pp. 668-673,

Fitzpatrick, K., J. Warner, M. Brewer, B. Louise, J.M. Barlow, and B. Sperry. (2015). *Treatments Used at Pedestrian Crossings of Public Transit Rail Services*. Transit Cooperative Research Program Web Document #3. National Academies of Science, Engineering and Medicine.

FHWA. (2018). *Railway-Highway Crossings (Section 130) Program*. Federal Highway Administration Office of Safety. Available: https://safety.fhwa.dot.gov/hsip/xings/

FHWA. (2002). *Guidance on Traffic Control Devices at Highway-Rail Grade Crossings*. U.S. Department of Transportation Highway Rail Grade Crossing Technical Working Group. Available:

https://safety.fhwa.dot.gov/intersection/other_topics/fhwasa09027/resources/Guidance%20On%20Traffic%20Control%20at%20Highway%20Rail%20Grade.pdf

FRA. (2018a). Characteristics of Trespassing Incidents in the United States (2012-2014). Report Number: DOT/FRA/ORD-18/24. Available at: https://www.fra.dot.gov/eLib/details/L19581#p1_z5_gD_lRT_ksuicide

FRA. (2018b). *2017 Highway-Rail Incidents by State*. Federal Rail Administration Office of Safety Analysis. Available: http://safetydata.fra.dot.gov/OfficeofSafety/publicsite/Query/gxrtally1.aspx

FRA. (2018c). *2017 Suicide Casualties by State*. Federal Rail Administration Office of Safety Analysis. Available: http://safetydata.fra.dot.gov/OfficeofSafety/publicsite/Query/gxrtally1.aspx

FRA. (2018d). U.S. DOT Crossing Inventory Forms. Available by site on the FRA GIS Safety Site at: https://fragis.fra.dot.gov/GISFRASafety/

FRA. (2017). *Highway Rail Incidents – Utah*. Available: http://safetydata.fra.dot.gov/OfficeofSafety/publicsite/Query/gxrtally1.aspx

Havarneanu, G., M.H. Bonneau, and J. Colliard. (2016). Lessons Learned from the Collaborative European Project RESTRAIL: Reduction of suicides and trespasses on RAILway property. *European Transport Research Review.* 8(2).

Havarneanu, G., J.M. Burkhardt, and A. Silla. (2017). Optimizing Suicide and Tresspass Prevention on Railways: A problem-solving model from the RESTRAIL project. *International Journal of Injury Control and Safety Promotion.* 24(4), 469-486.

Jeng, O.J. (2005). Human Factors Evaluation of Design Ideas for Prevention of Vehicles Entrapment on Railroad Tracks Due to Improper Left Turns. New Jersey Department of Transportation. Report # FHWA-NJ-2005-019. Available at: https://www.state.nj.us/transportation/refdata/research/reports/FHWA-NJ-2005-019.pdf

Kuzel, M., M. Heller, and J.B. Sala. (2008). *A Review of Real-World Collisions Involving Distracted Pedestrians*. Proceedings of the Annual Occupational Ergonomics and Safety Conference, Chicago.

Lichenstein, R., D.C. Smith, and J.L. Ambrose. (2012). Headphone Use and Pedestrian Injury and Death in the United States: 2004-2011. *Journal of Injury Prevention*, 18(5), pp 287-290.

Lobb, B. (2006). Trespassing on the Tracks: A review of railway pedestrian safety research. *Journal of Safety Research*, 37(4), pp. 359-365.

Lobb, B., N. Harré, and N. Terry. (2003). An Evaluation of Four Types of Railway Pedestrian Crossing Safety Intervention. *Journal of Accident Analysis and Prevention*, 35(4), pp. 487-494.

McPherson, C., M. Daff, and S.K. Merz. (2005). Pedestrian Behavior and the Design of Accessible Rail Crossings. Proceedings of the 28th Annual Australasian Transport Research Forum. Available: http://atrf.info/papers/2005/2005_McPherson_Daff.pdf

Metaxatos P. and P.S. Sriraj. (2015). Pedestrian Safety t Rail Grade Crossings: Focus Areas for Research and Intervention. *Urban Rail Transit*, 1(4), pp.238-248.

Mwakalonge, J. S. Siuhi, and J. White. (2015). Distracted Walking: Examining the extent to pedestrian safety problems. *Journal of Traffic and Transportation Engineering*. 2(5), pp. 327-337.

NCSS Statistical Software. (2018). *Poisson Regression*. Accessed at: http://ncss.wpengine.netdna-cdn.com/wp-content/themes/ncss/pdf/Procedures/NCSS/Poisson_Regression.pdf

NTSB. (2017). *NTSB 2017-2018 Most Wanted List of Transportation Safety Improvements*. Available: https://www.ntsb.gov/safety/mwl/Documents/2017-18/MWL-Brochure2017-18.pdf

NTSB. (2016). US Transportation Fatalities in 2016 – By mode. Available: https://www.ntsb.gov/investigations/data/PublishingImages/US-TransportationFatalities2016.jpg

Ogden, B.D. (2007). *Railroad-Highway Grade Crossing Handbook*. Institute of Transportation Engineers for the Federal Highway Administration. Report # FHWA-SA-07-010. Available: https://www.fra.dot.gov/Elib/Document/1464.

Operation Lifesaver. (2016). *2016 Annual Report*. Available: https://s3.amazonaws.com/download.oli.org/Annual+Report/2016_OLI_AnnualReport_web.pdf

Saelens, B., J.F. Sallis, and L.D. Frank. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*. 25:2, 80-91.

Sposato, S., P. Bien-Aime, and M. Chaudhary. (2006). *Public Education and Enforcement Research Study*. Report DOT-VNTSC-FRA-06-03. U.S. Department of Transportation and Innovative Technology Administration, John A. Volpe National Transportation Systems Center, Cambridge.

Standards Australia. (1993). AS1742.7 *Manual of Uniform Traffic Control Devices - Railway Crossings*.

UDOT. (2013). *Pedestrian Grade Crossing Manual*. Available: https://www.udot.utah.gov/main/uconowner.gf?n=12635319754536158

UDOT. (2017). *Preempting Traffic Signals Near Railroad Crossings in Utah*. January 2017. Available: https://www.udot.utah.gov/main/uconowner.gf?n=29256830125849243

UDOT. (2016). *Railroad Safety FAQ*. April 2016. Available at: https://www.udot.utah.gov/main/f?p=100:pg:0:::V,T:,1951

UDPS. (2016). *Utah Crash Summary 2016*. Utah Department of Public Safety: Highway Safety Office. Available: https://highwaysafety.utah.gov/wp-content/uploads/sites/22/2015/02/UtahCrashSummary2016-2.pdf

Urbanik, T., and A. Tanaka. (2017). *Traffic Signal Preemption at Intersections Near Highway-Rail Grade Crossings*. Washington D.C.: The National Academies Press. Synthesis #507. National Academies of Science, Engineering and Medicine. Available: http://nap.edu/24769

U.S. Census Bureau (2016). *Journey to work characteristics, 2016 American Community Survey 1-year estimates.* Retrieved from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_17_1YR_B08301&prodType=table

U.S. Census Bureau (2018). *Selected economic characteristics, 2015 American Community Survey 1-year estimates.* Retrieved from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_1YR_DP03&prodType=table

U.S. Code of Federal Regulations. (2015). *49 CFR § 218.93 - DEFINITIONS*. Available at: https://www.gpo.gov/fdsys/search/pagedetails.action?collectionCode=CFR&searchPath=Title+49&granuleId=CFR-2015-title49-vol4-sec218-93&packageId=CFR-2015-title49-vol4&oldPath=Title+49&fromPageDetails=true&collapse=true&ycord=1688

Wheelchair Safety at Rail Level Crossings Task Force. (2002). *Report to the Minister for Transport*. Victorian Department of Infrastructure: Melbourne.